ERA – Clemson University Cool Roof & Sustainability

Dhaval Gajjar, PhD, FMP, SFP **Vivek Sharma, PhD, LEED - AP**

Nieri Family Department of Construction Science and Management
Clemson University

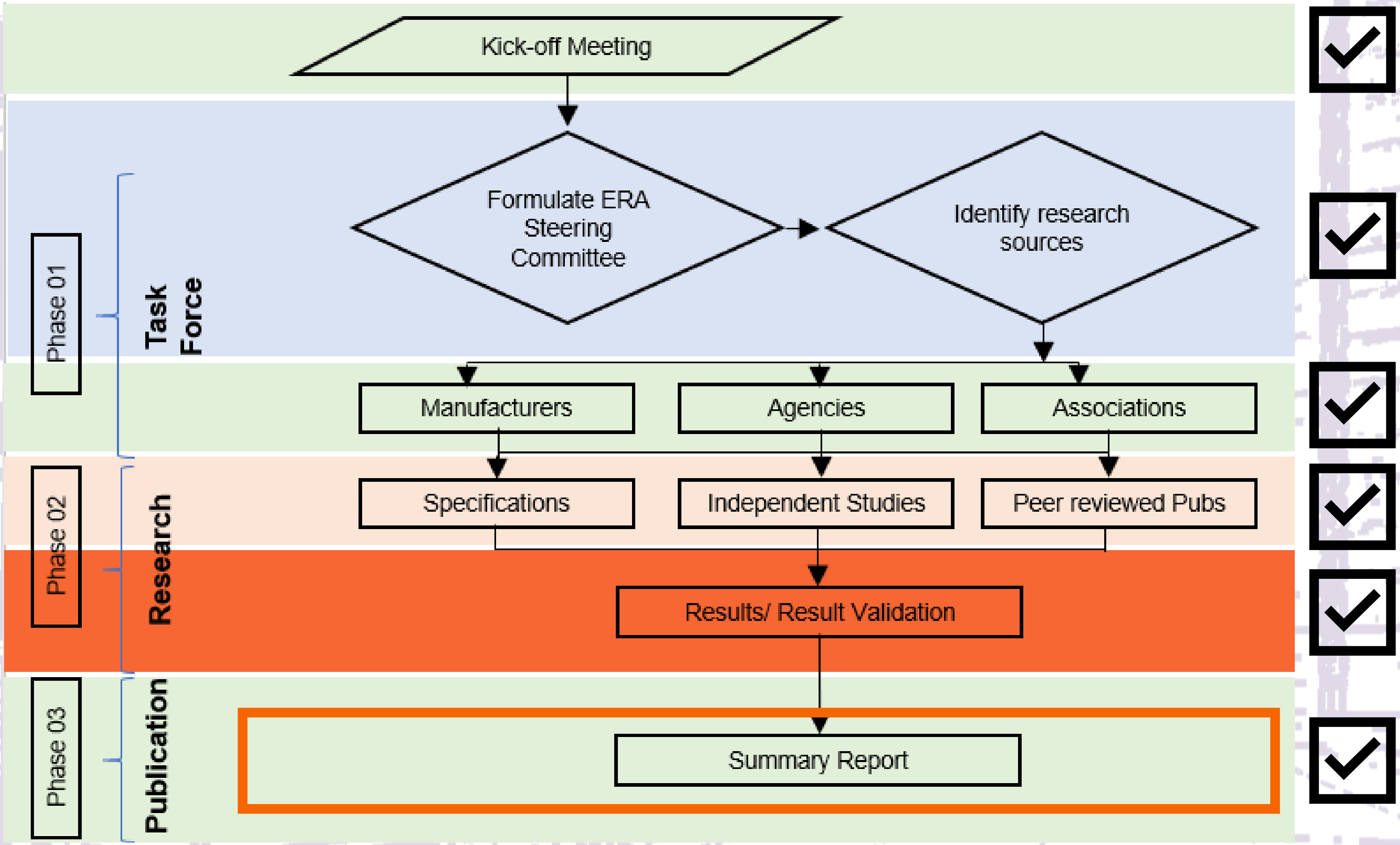
EPDM ROOFING ASSOCIATION

Nieri Family Department of CONSTRUCTION SCIENCE AND MANAGEMENT

Objective

Conduct a thorough investigation of published data and models to understand the impact of membrane color on cool roof efficiency and its overall impact on urban heat island effect

Approach



EPDM ROOFING ASSOCIATION

Cool Roof Studies – Energy Efficiency and Urban Heat Island Effect

S. No.	Database	Number of articles	Key words and Inclusion criteria	Number of included papers
1	Engineering Village	178	"cool roof" AND "energy efficiency" "cool roof" AND "urban heat island effect" "cool roof" AND " life cycle" Peer reviewed, Title, Abstract The studies were included on the basis of effect on energy efficiency in terms of savings in cooling/heating energy usage, $ savings, temperature reductions, urban heat island effect reductions.	13
2	ProQuest	287		7
3	ACM Digital Library	1		0
4	Web of Science	234		13
5	Business Source Complete	20		2
6	Academic Search Complete	97		15
7	Berkeley Lab Heat Island Group	165		14
8	Springer Link	172		9
9	IEEE	32		2
10	Wiley Online Library	71		2
11	OSTI	121		8
12	Clemson Library	313		17
	Total	**1,691**		**102**

Built Environment Studies

S. No.	Database	Number of articles	Key words and Inclusion criteria	Number of included papers
1	Engineering Village	75	"Built Environment" AND "Life Cycle" "Built Environment" AND "Energy Efficiency", "Built Environment" AND "Urban Heat Island Effect", Peer reviewed, Title, Abstract	11
2	ProQuest	300		63
3	ACM Digital Library	300		12
4	Web of Science	0		0
5	Business Source Complete	50		10
6	Academic Search Complete	30		0
7	Nexis Uni	10		2
8	Springer Link	300		70
9	IEEE	75		5
10	Wiley Online Library	0		0
11	OSTI	25		5
	Total	**1,165**		**178**

Framework to document impact of Cool Roof on EE and UHIE

01	02	03	04	05
Type and Sample Size	**Location/ Climate/ Temperature range**	**Property of roof**	**Color of roof**	**Duration of data capture**
Type of roof and number of study sample.	Organize studies based on climate/ temperature range of the location.	Age of the roof, low/steep slope roof	Albedo value, solar reflectance	How long was the roof sample monitored?
Effect on energy efficiency roof type i. TPO/EPDM/PVC ii. Built-up Roofs iii. Metal Roofs iv. Asphalt Shingles v. Concrete Roofs vi. Clay Tiles	Study the effect of location (climate zone and temperature) on energy efficiency.	Adjustment of reflectance based on the age of roof.	Study the effect of reflectance and albedo on energy efficiency of roof.	Study the different duration of data monitoring for simulation and real world studies to draw limitations of the studies.

Framework to document impact of Cool Roof on EE and UHIE

06	07	08	09	10
Case Study vs. Simulation	**Limitations / Findings**	**Effect on Energy Efficiency (EE)**	**Effect on Urban Heat Island Effect**	**Future Path**
Validity of study methods (software or model)	What are the findings and how are they supported?	How various roofs affect EE?	What is the impact of roofs on UHIE?	Areas of further exploration.
Analyze the different methods used to conduct experiments.	List the limitations mentioned in the publication and by observation.	Study the effect of various parameters on energy efficiency of the roof in terms of energy usage and temperature reductions.	Study UHIE by analyzing - i. Temperature, heat flux, ozone concentration reduction ii. Annual energy cost savings iii. CO2 emissions iv. Urban Canyon temperature	List the future path mentioned in the publications.

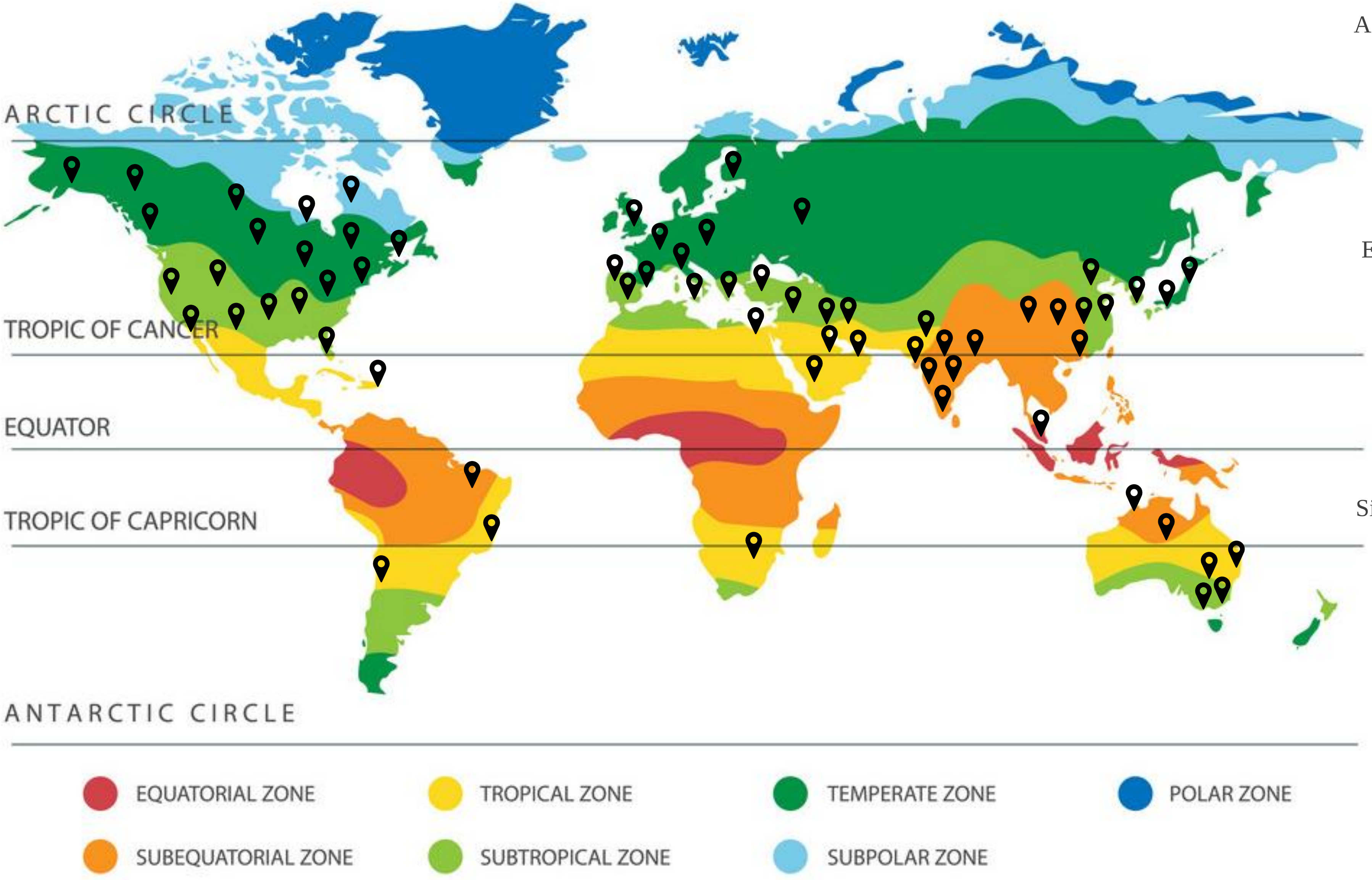
EPDM ROOFING ASSOCIATION

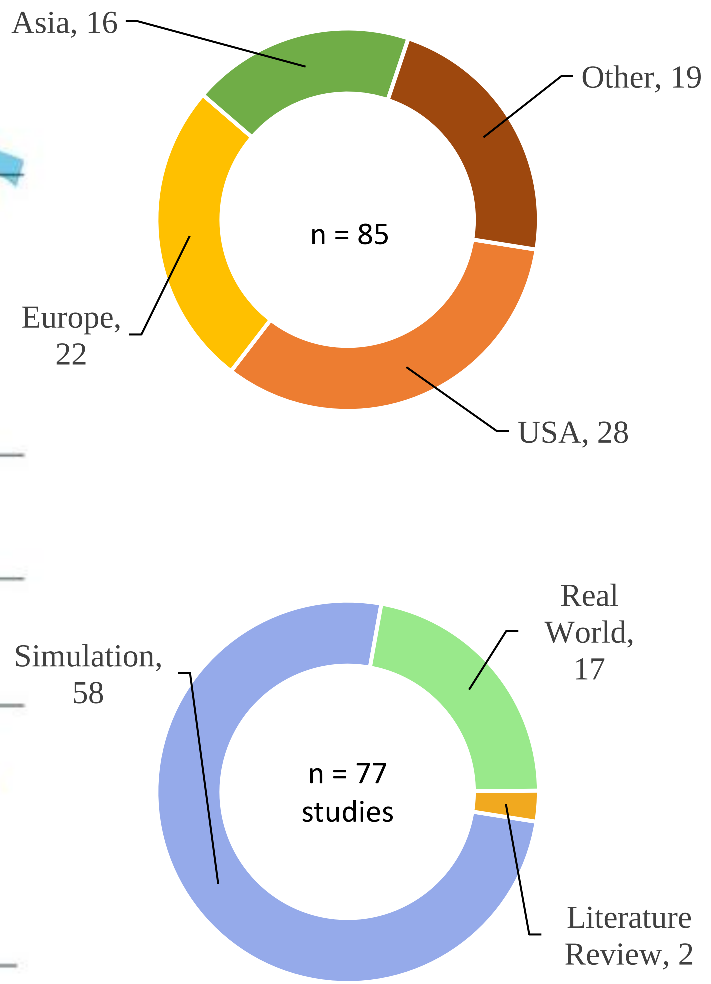
* Case study is synonymous with Real World study.

Nieri Family Department of CONSTRUCTION SCIENCE AND MANAGEMENT

Energy Efficiency

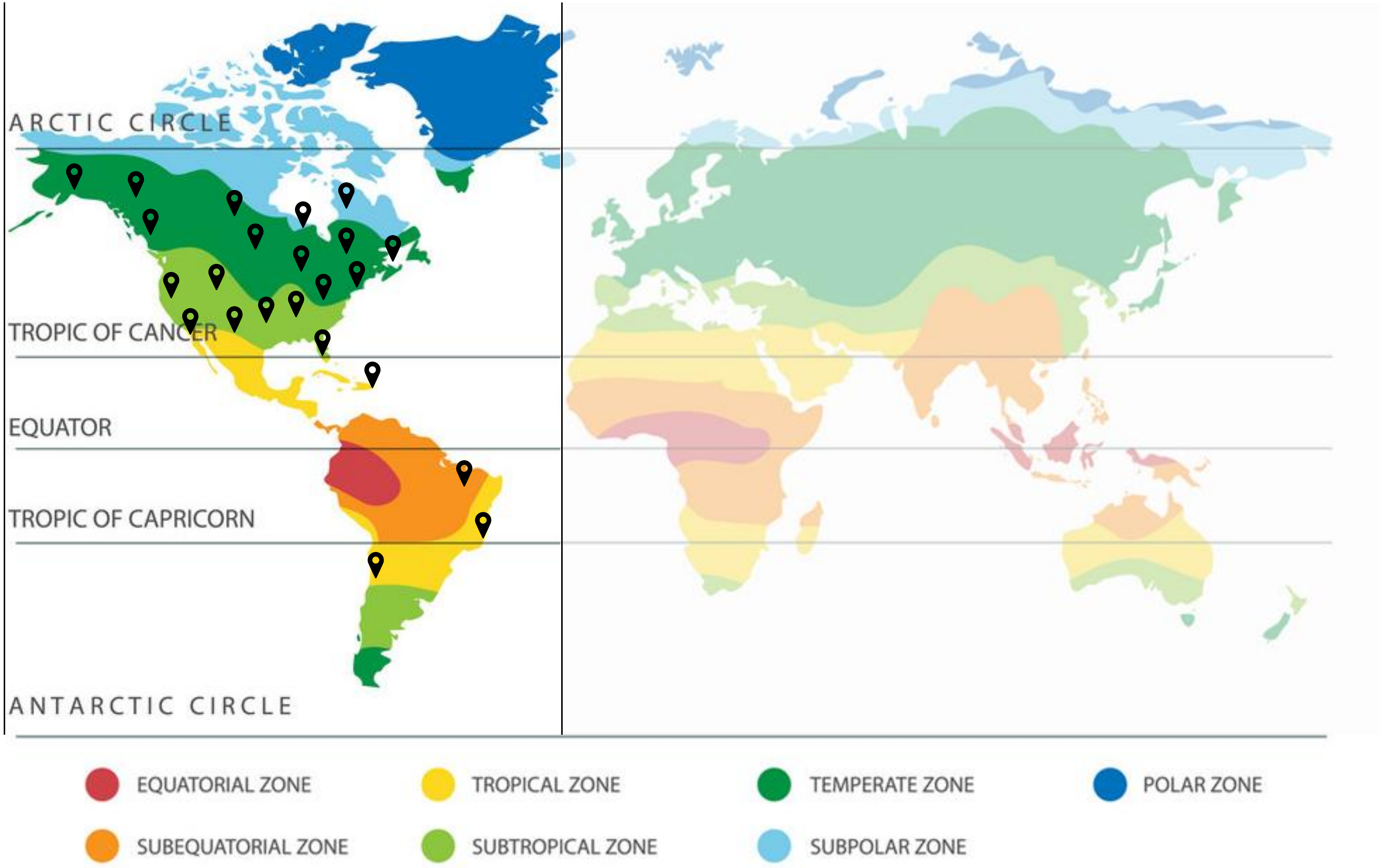
Types and Locations of studies





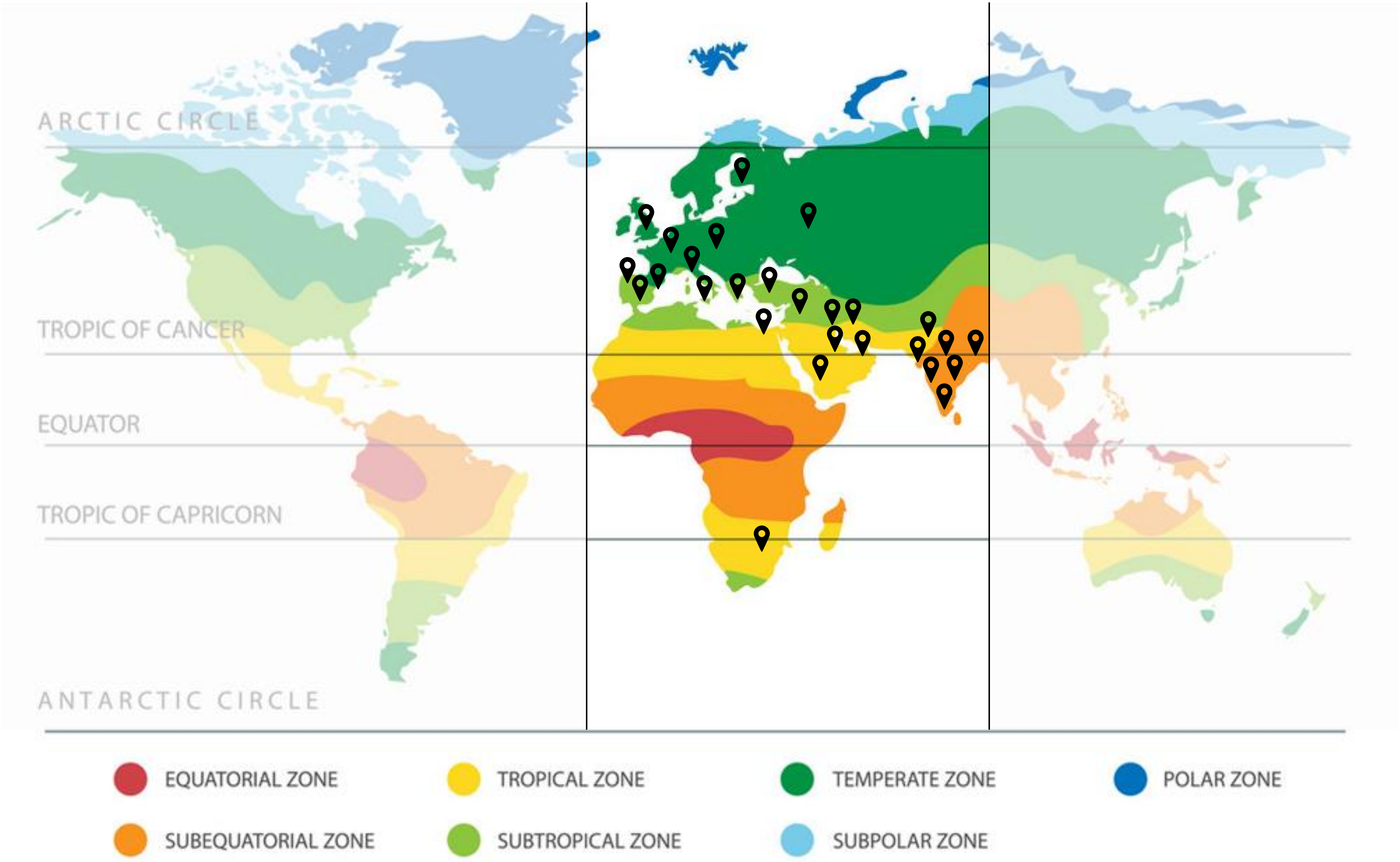
Types of Studies & Location

Number of studies in North and South America



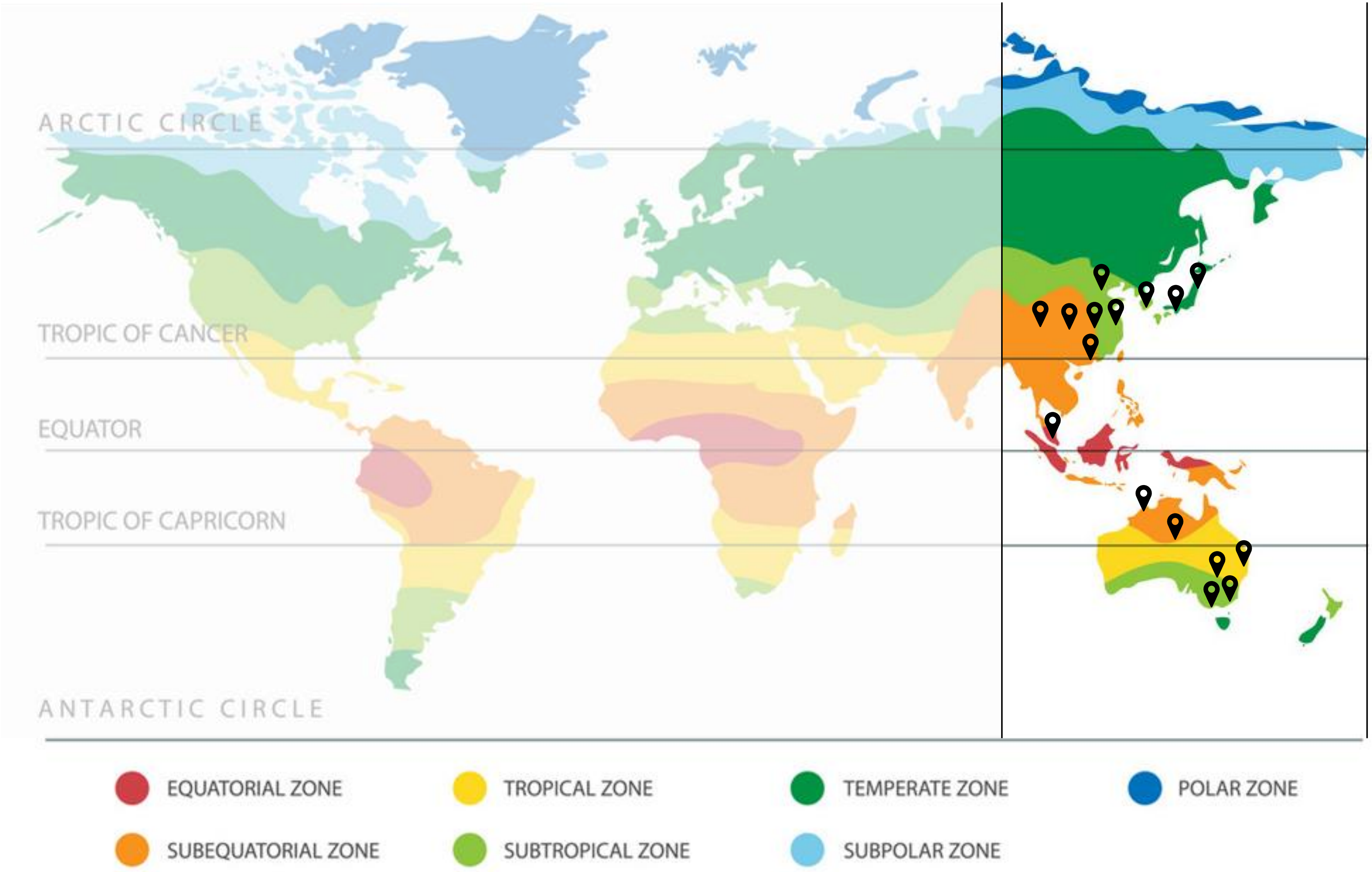
Number of Studies (n) - 33

Number of studies in Europe, Africa and parts of Asia



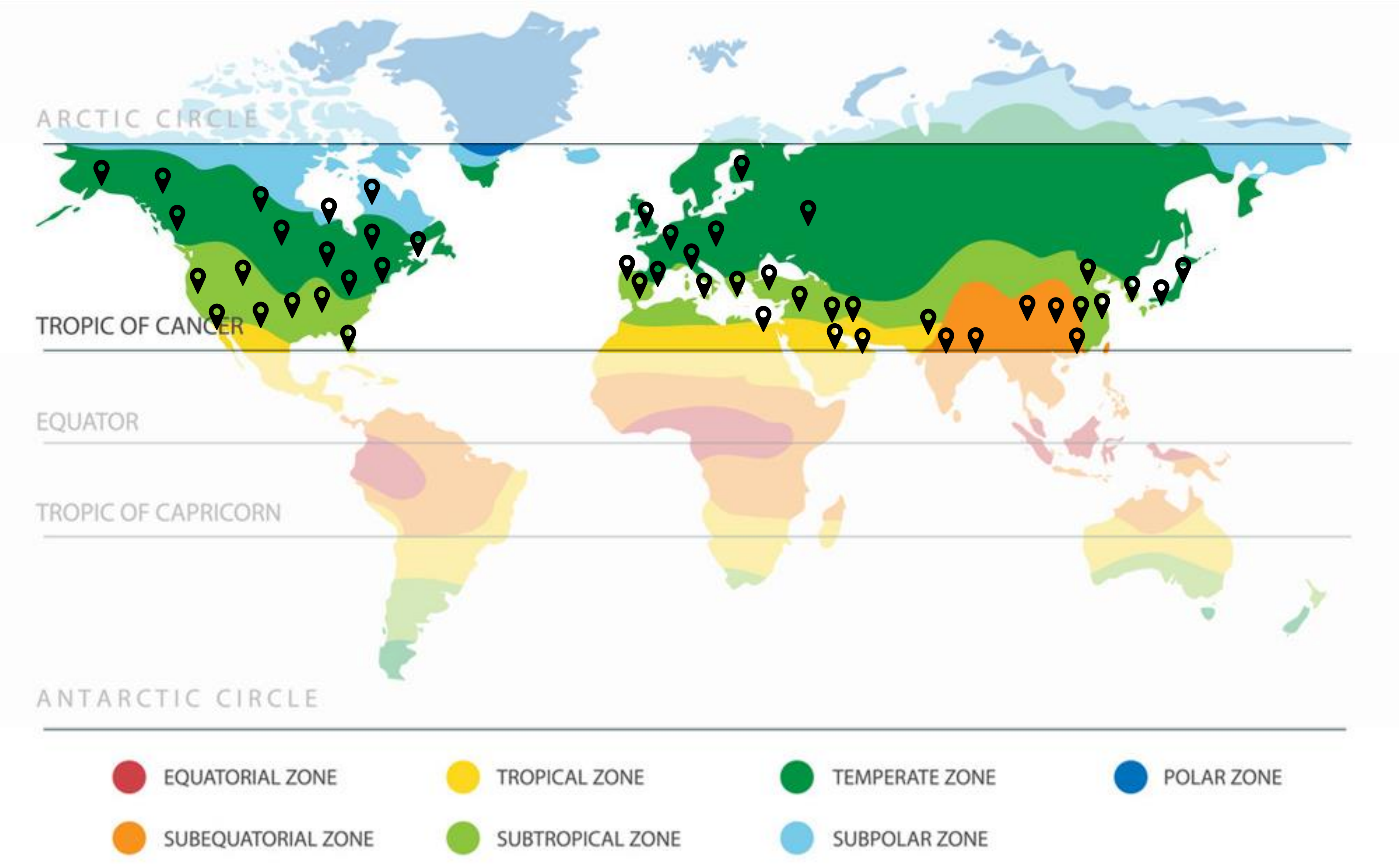
Number of Studies (n) - 26

Number of studies in Australia and parts of Asia



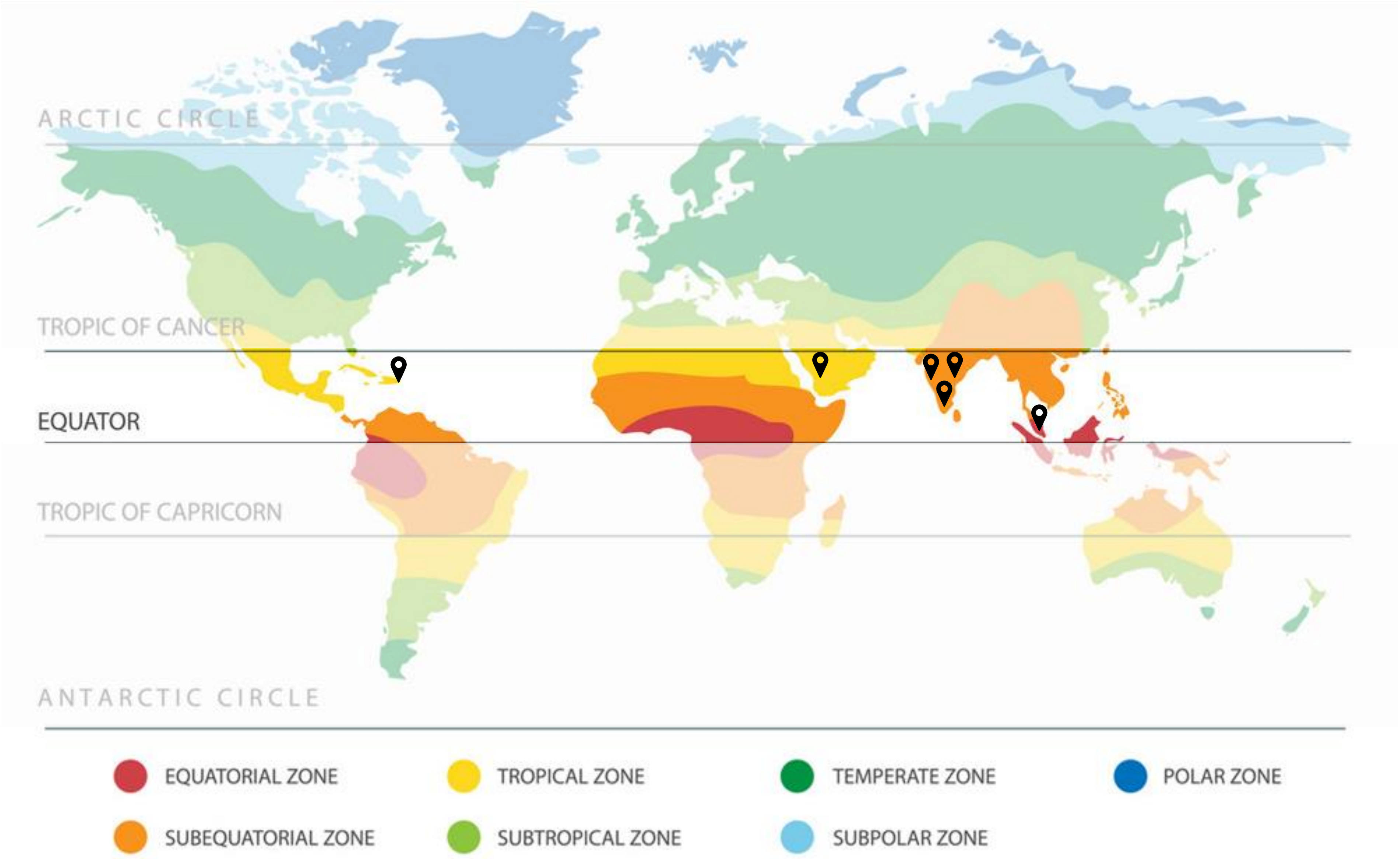
Number of Studies (n) - 14

Number of Studies between Arctic Circle and Tropic of Cancer



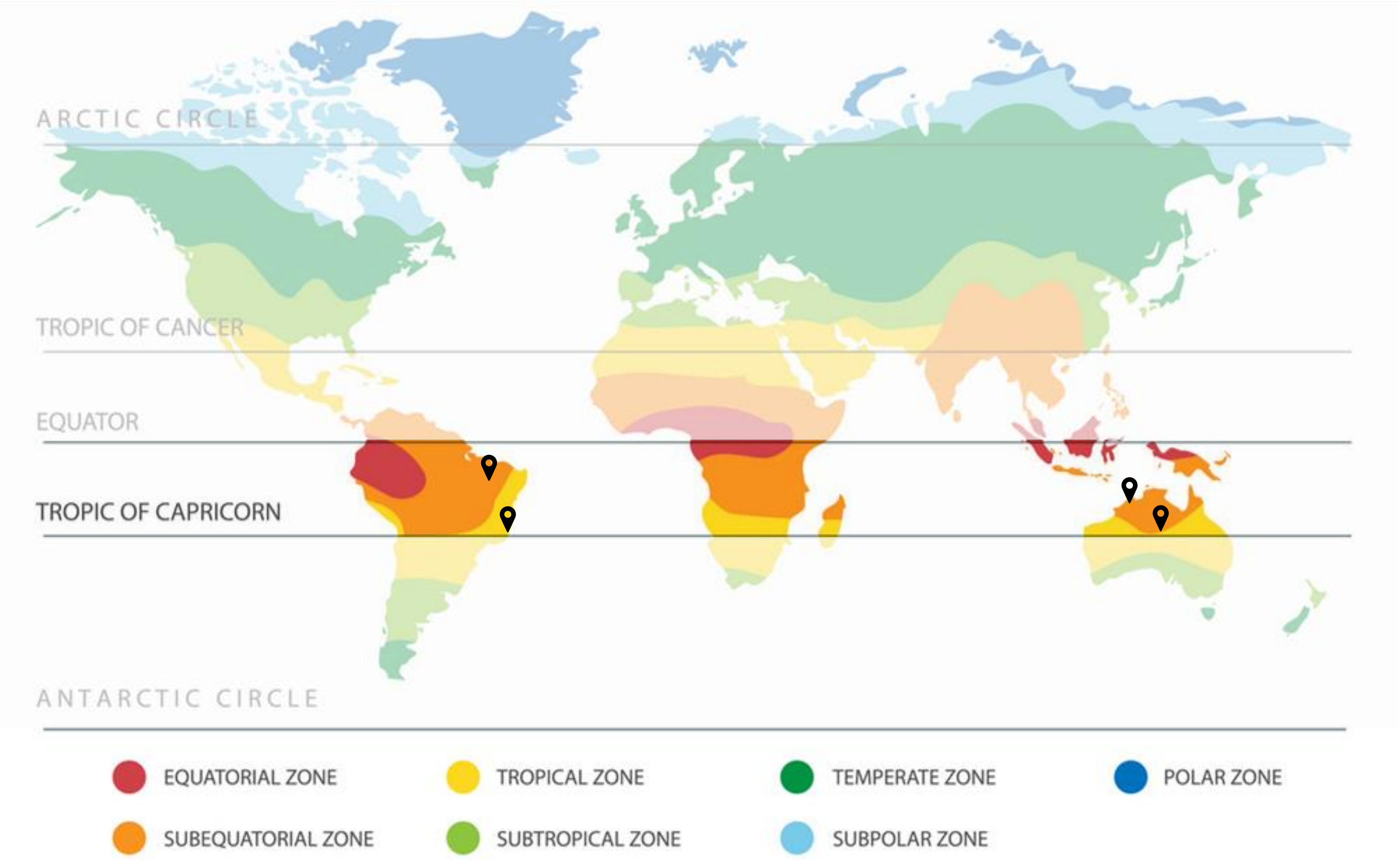
Number of Studies between Arctic Circle and Tropic of Cancer (n) - 56

Number of Studies between Tropic of Cancer and Equator



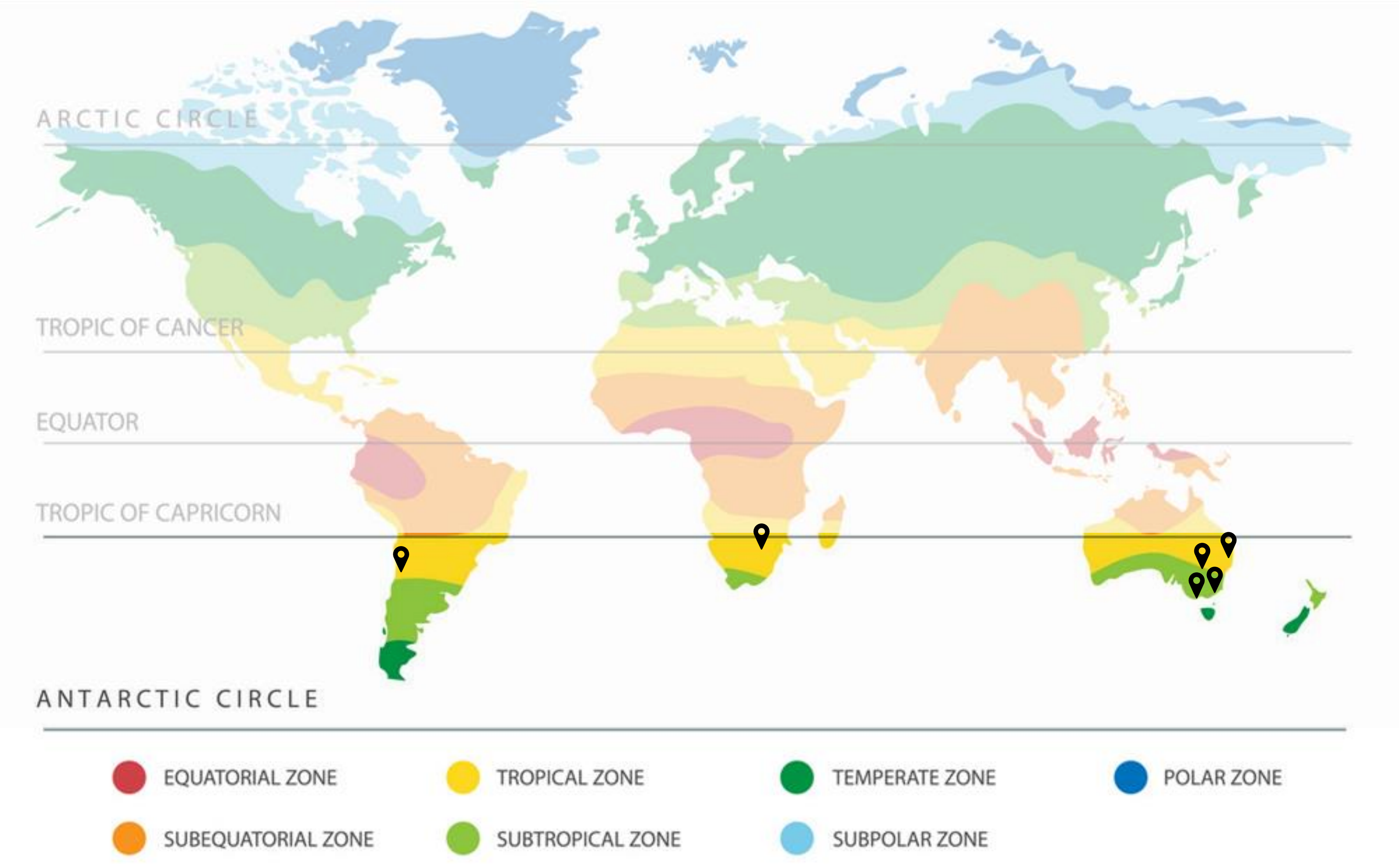
Number of Studies between Tropic of Cancer and Equator (n) - 9

Number of Studies between Equator and Tropic of Capricorn



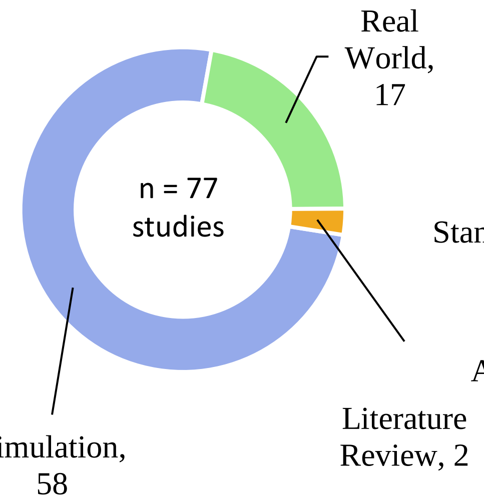
Number of Studies between Equator and Tropic of Capricorn (n) – 5

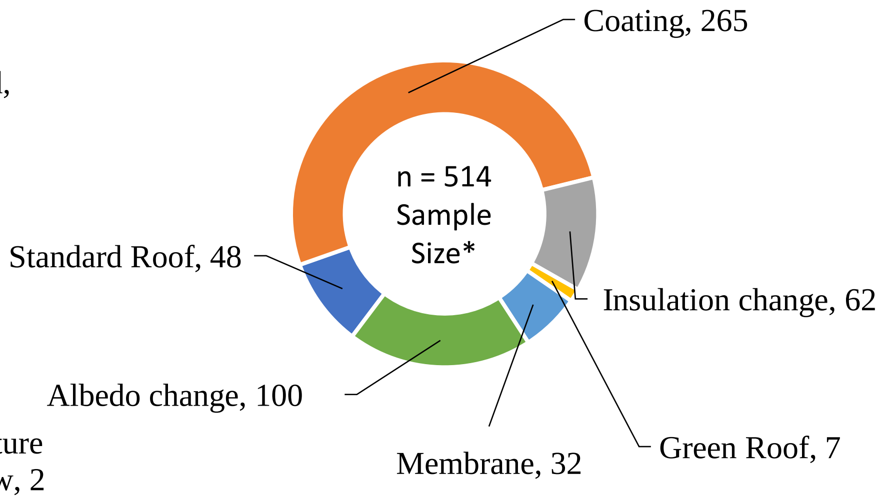
Number of Studies between Tropic of Capricorn and Antarctic Circle



Number of Studies between Tropic of Capricorn and Antarctic Circle – 6

Types and Basis of Studies





# of Studies – 77 studies
# of Roofs Included in the Studies - 509 sample size*

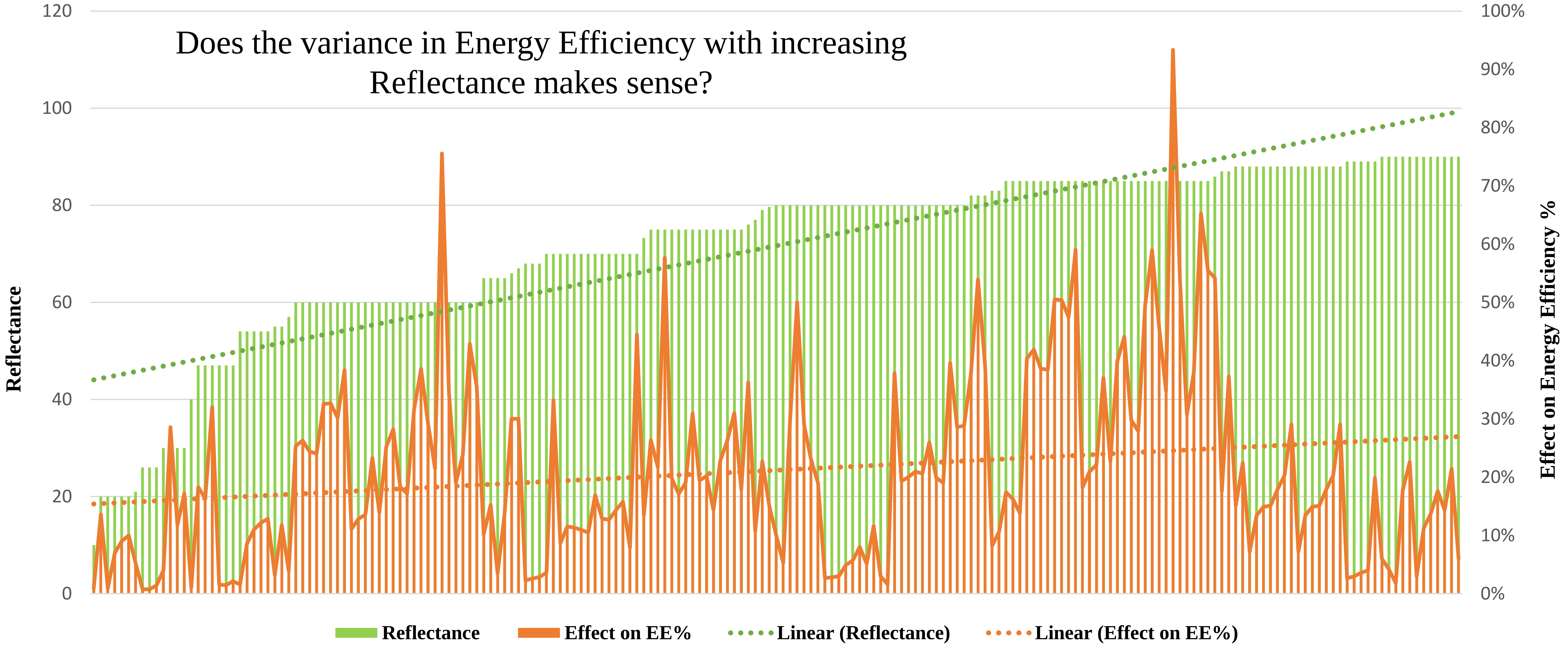
Types of modifications done on different roof types

- Standard Roof – Baseline case (for e.g., comparison of black roof with cool roof)
- Coating – coating the existing roof with cool paint
- Membrane – modification to the existing roof surface
- Albedo change (membrane/coating application) – measuring effect of albedo (range 0.23 – 0.8) on EE
- Insulation change – measuring effect on EE by changing insulation
- Green Roof – comparing a green roof with standard roof

*Sample Size – Individual Instances of Roof Included in Studies

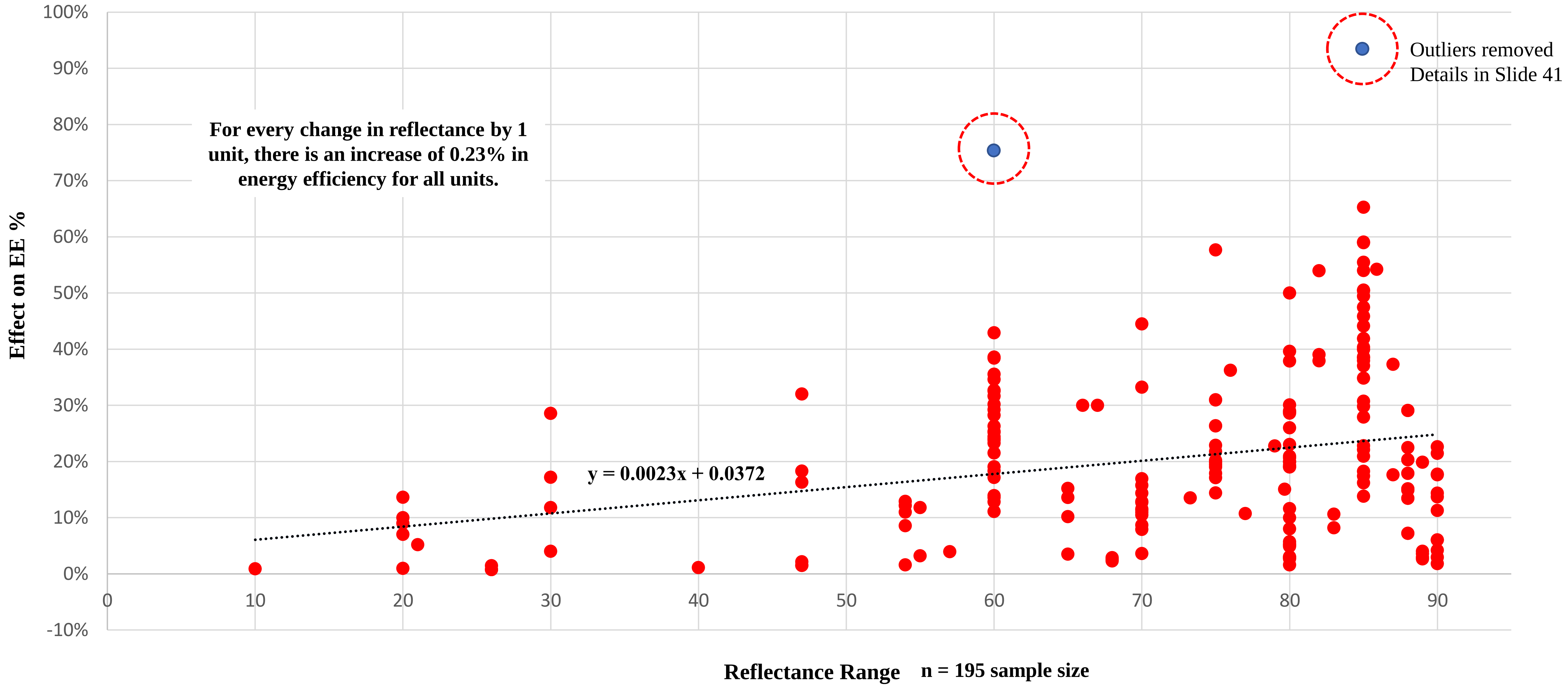
S. No.	Type of Simulation Model	# of studies
1	Analytical Method	1
2	Autodesk Green Building Studio	1
3	Community Earth System Model	1
4	Complex Fast Fourier Transform	1
5	CoolCalkPeak	1
6	DOE 2.1	8
7	Energy Plus	21
8	Envi Met	2
9	HASP/ACLD-β	1
10	Heat Transfer Model	1
12	hygIRC-C	1
13	Integrated Environmental Solutions	2
14	Je Plus	1
15	MATLAB	1
16	MUKLIMO 3	1
17	STAR	2
18	THERB	1
19	Trnsys	7
20	WRF	4
Total		**58**

Effect of Reflectance on Energy Efficiency (All roofs, All colors, All units)



* This graph covers data for all types of roofs and all colors of roof modifications. Energy efficiency includes both energy consumption reduction and temperature reduction.

Effect of Reflectance on Energy Efficiency* (All roofs, All colors, All units)

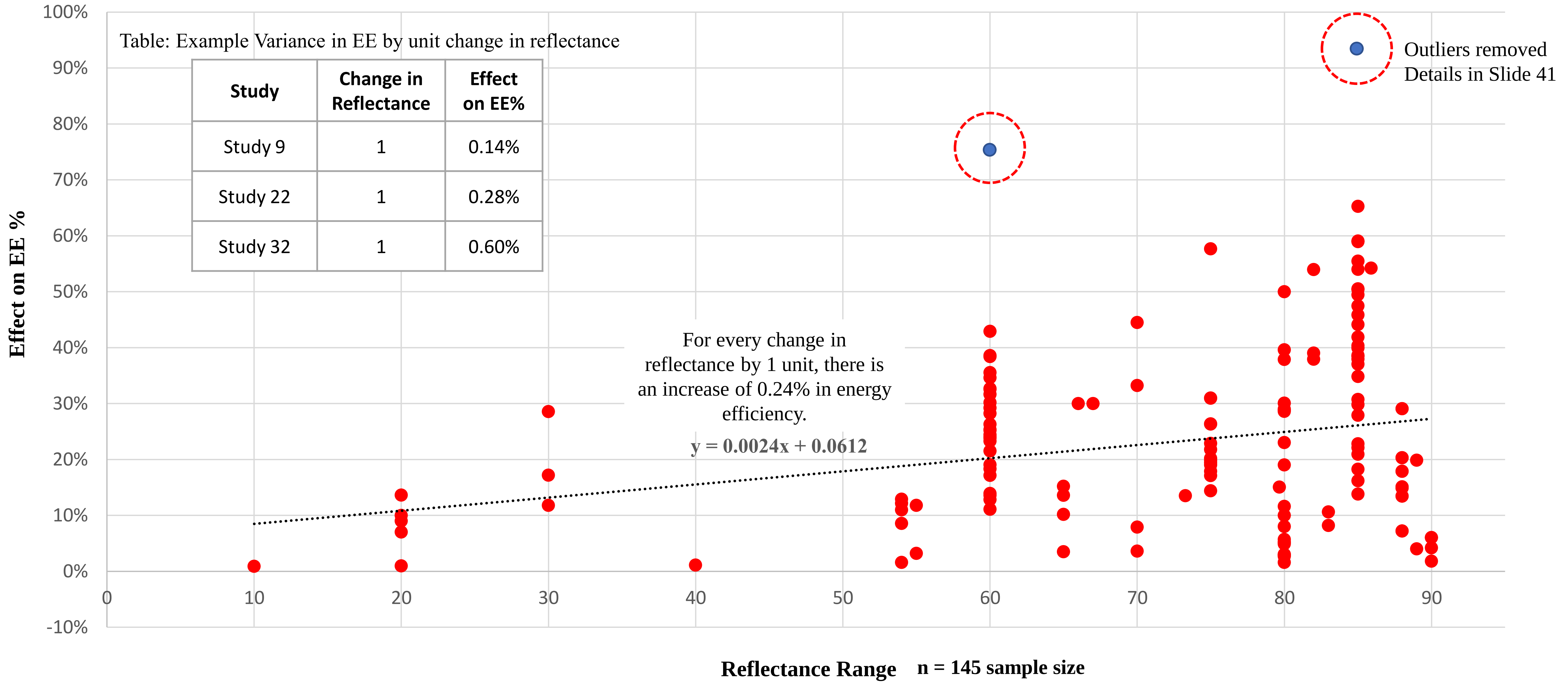


* Energy efficiency here is defined as percentage difference in energy consumption or temperature reduction. The chart does not consider months and climate zone of data capture.

Effect of Reflectance on Energy Efficiency* (All roofs, All colors, Energy unit)

Table: Example Variance in EE by unit change in reflectance

Study	Change in Reflectance	Effect on EE%
Study 9	1	0.14%
Study 22	1	0.28%
Study 32	1	0.60%



* Energy efficiency here is defined as percentage difference in energy consumption. For e.g., KWh, KWh/sqm, KWh/sqm/year etc. The chart does not consider months and climate zone of data capture.

Effect of Albedo* on Energy Efficiency** (All roofs, All colors, All units)

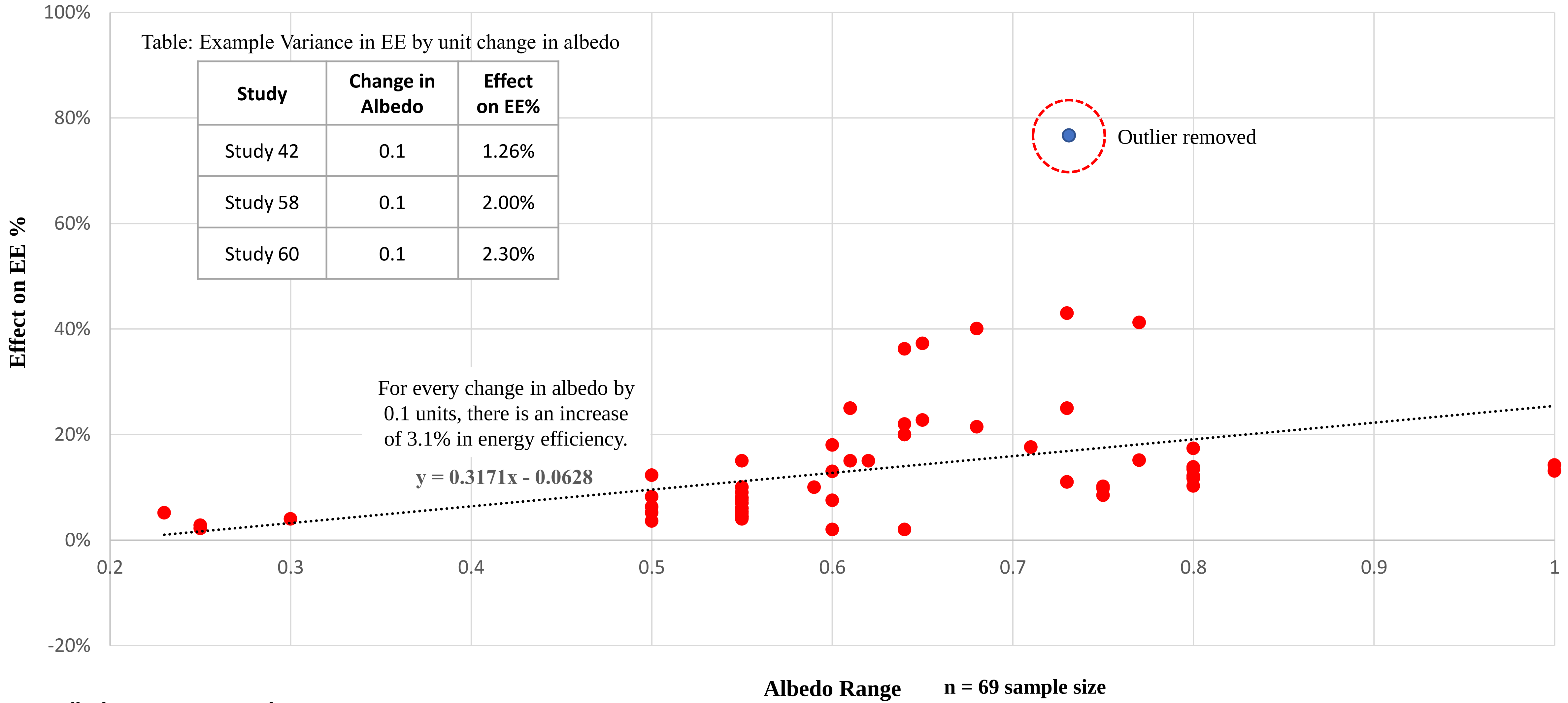


Table: Example Variance in EE by unit change in albedo

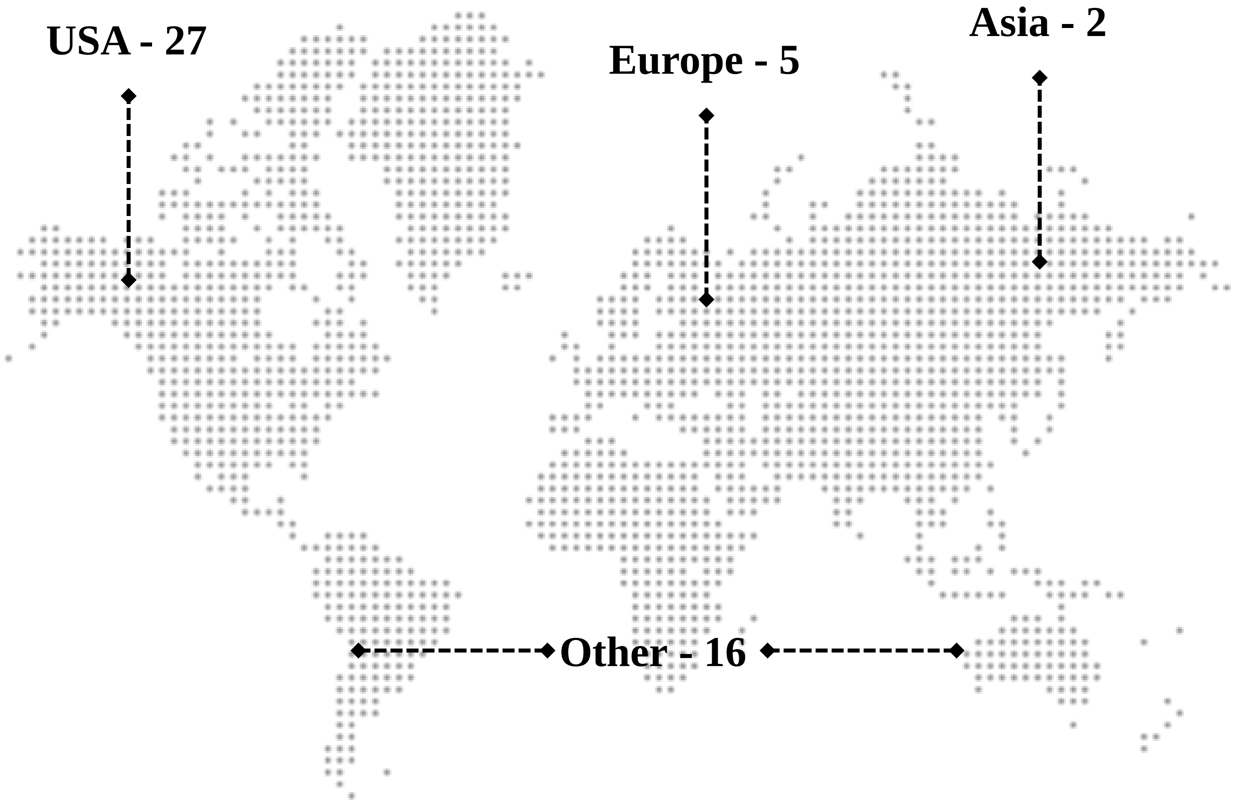
Study	Change in Albedo	Effect on EE%
Study 42	0.1	1.26%
Study 58	0.1	2.00%
Study 60	0.1	2.30%

*Albedo in Latin means whiteness

** Energy efficiency here is defined as percentage difference in energy consumption or temperature reduction. The chart does not consider months and climate zone of data capture.

Built-up Roofs

Built-up Roofs – Area and Type of Studies

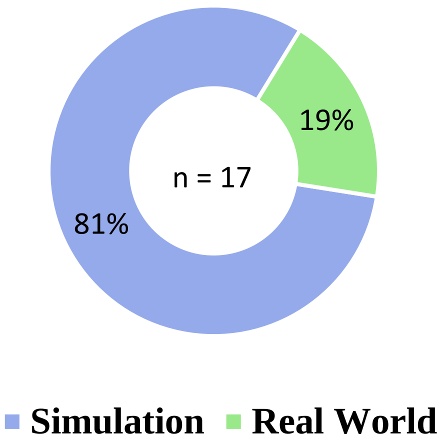


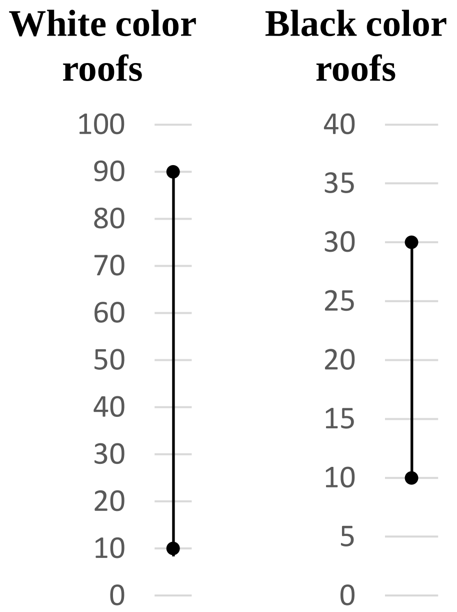
Sample size - 50

Total Area Studied – 355,047 SF
Average Area Studied – 13,150 SF

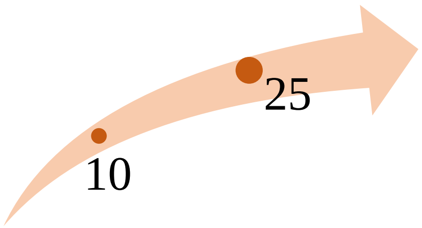
Total No. of Studies – 17
Simulation – 13
Real World - 4

Types of Studies





Reflectance



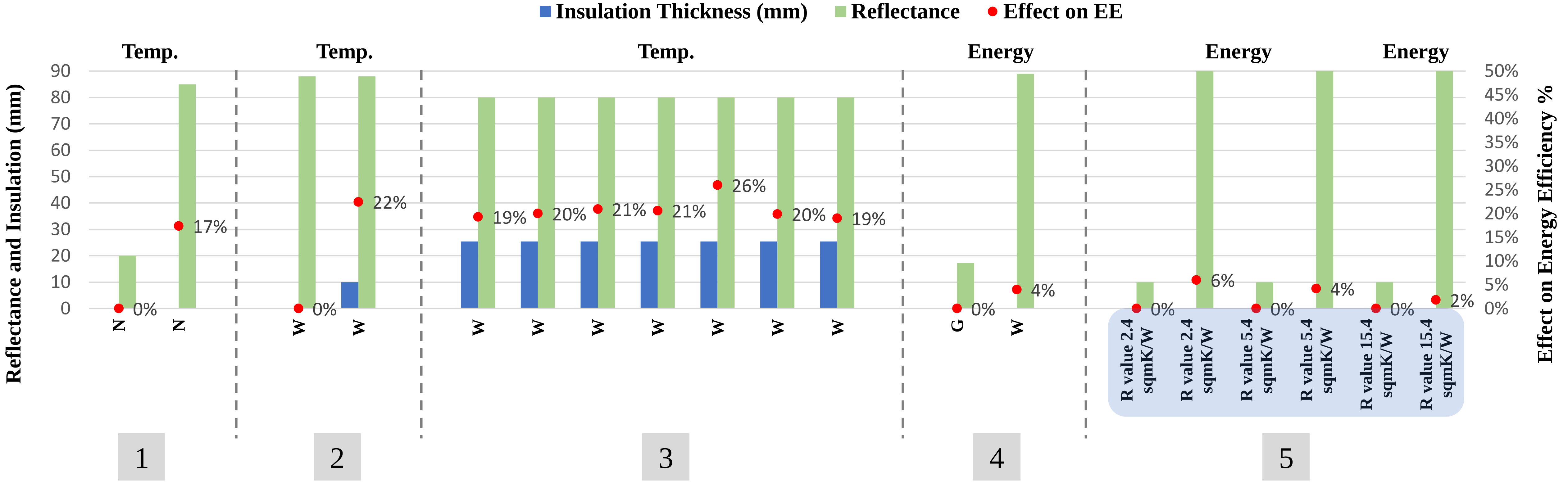
Insulation Thickness (mm)

Location, temperature range, month and duration of data capture

No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture	No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture
1	Beijing	2	72 - 88	July	3	14	Minneapolis	1	9 - 83	July	7
2	Calgary	1	12 - 75	Jan - Dec	0*	15	Montreal	9	9 - 79	Jan - Dec	0*
3	California	2	48 - 85	Jan - Dec	0*	16	New Jersey	1	26 - 86	Aug/Jan	2**
4	Chicago	1	22 - 83	July	7	17	New York	1	28 - 85	July	1**
5	Fargo	1	2 - 83	July	7	18	Phoenix	5	45 - 107	Jan - Dec	0*
6	Florida	5	78 - 88	July - Aug	7**	19	Saskatoon	1	-3 - 78	Jan - Dec	0*
7	France	2	65 - 77	Jun - Aug	80	20	Seattle	2	37 - 79	Jan - Dec	0*
8	Greece	2	72 - 90	July	20**	21	St. Johns	1	19 - 69	Jan - Dec	0*
9	Houston	1	47 - 95	July	7	22	Toronto	2	17 - 78	Jan - Dec	0*
10	Jamaica	1	75 - 88	Jan - June	150	23	Tucson	4	76 - 100	July	10
11	London	1	46 - 72	May - July	90	24	Vancouver	1	36 - 83	Jan - Dec	0*
12	Los Angeles	1	48 - 85	July	7	25	Wilmington	1	37 - 89	Jan - Dec	0*
13	Miami	1	62 - 90	7	July						

*0 days assumed 365 days of analysis (all simulation-based)
**Real world studies
17 studies 50 sample size

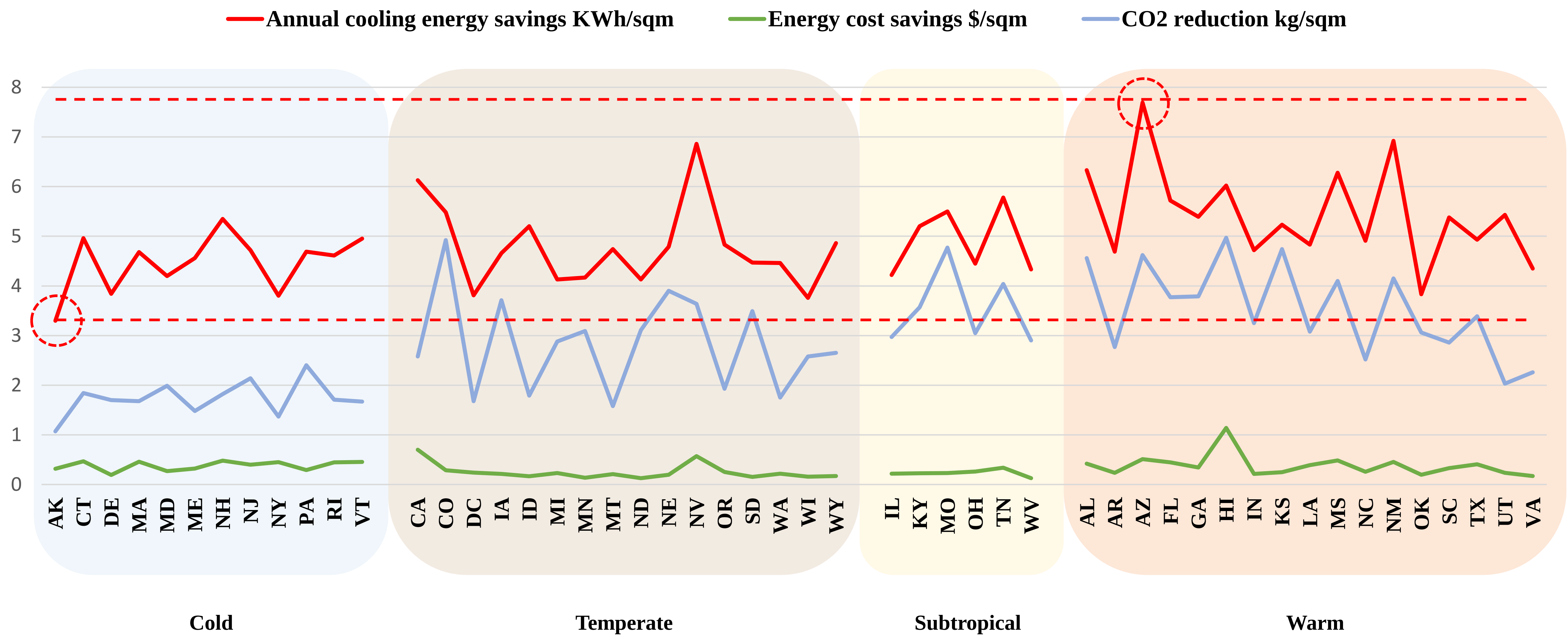
Built-up Roofs – Effect of Reflectance and Insulation on Energy Efficiency



N – Roof color not mentioned   W – White color roof   G – Gray color roof   #1 to #5 – Individual Studies

• Beijing – warm temperate zone • For every change in reflectance by 1 unit there is 0.26% of temperature reduction.	• 2 modifications – cool paint with and without insulation. *0% shows the baseline case with no insulation.	• 1 modification – 7 locations in USA and Canada – cool paint coating on Built-up Roof – Seattle has abnormal value of 26% reduction in temperature – no details on this value • A smaller baseline value of temperature of a standard roof yields in higher % reduction in temperature.	• Coating gray roof with white cool paint to increase reflectance from 17.2 to 89 in Greece.	• 3 modifications – Montreal - insulation with changing solar reflectance show net annual energy savings. • The importance of reflectance overweighs the importance of insulation level in roof design. • Low solar reflectance with high level insulation is best design for cold climate like Montreal.

Built-up roof – Effect of albedo change from 0.2 to 0.55 [Levinson et. al, 2009]



- Simulation based study – study the effect of modification of roof albedo from 0.2 to 0.55 with the use of cool white paint
- Alaska – coldest state – lowest annual cooling energy savings in KWh/sqm
- Arizona – hottest state – highest annual cooling energy savings in KWh/sqm

Limitations and Future Path

Limitations by Publications

- During the summer, the building was naturally ventilated and influenced by indirect effects that were not assessed in the study (Bozonnet et al., 2011)
- The results in the study apply to a specific roofing type and climatic conditions (Saber et al., 2012)
- The study limits to one building and assumes that indirect rooftop cooling will impact the whole building (Virk et al., 2015)

Limitations by Observation

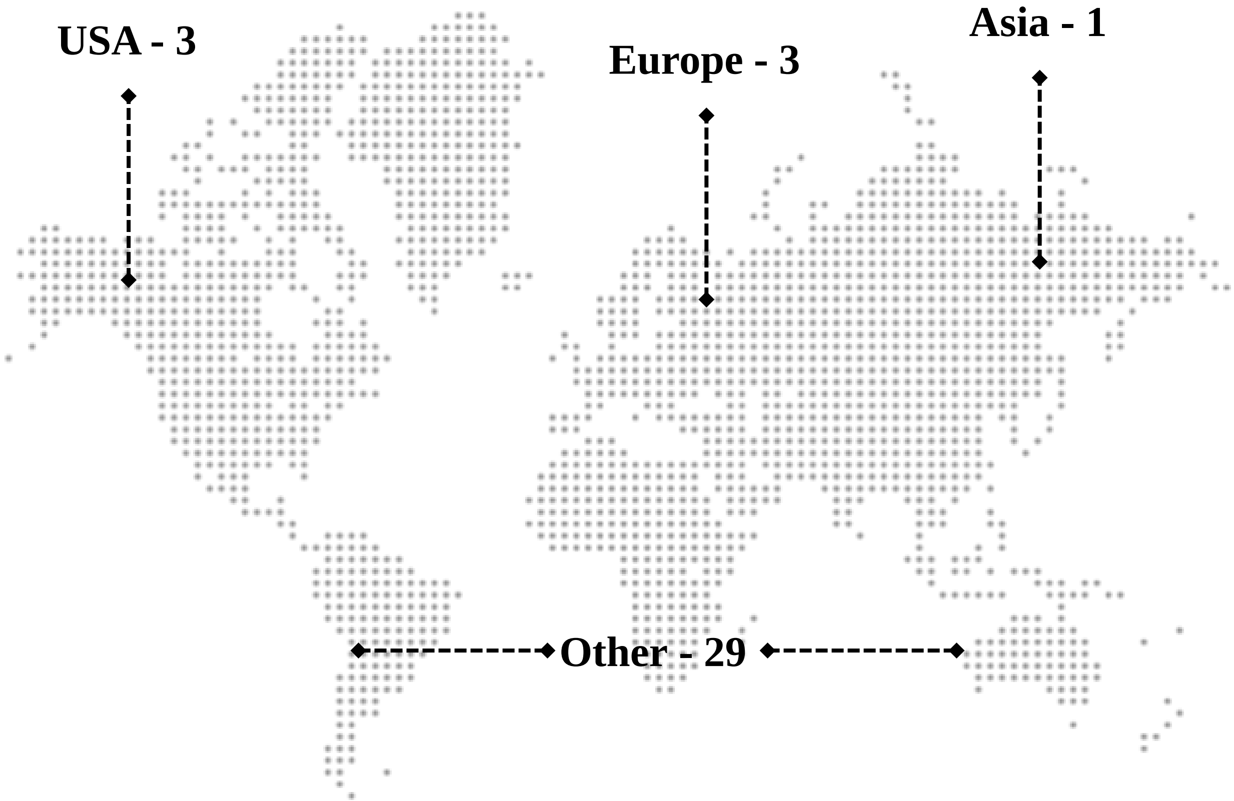
- Mostly simulation-based studies.
- Majority of the studies utilize minimal data capture duration during specific months to draw conclusions for annual roof performance.
- Data duration capture and the corresponding analysis focused mostly during summer months.
- Studies focused during summer months show higher energy savings and consideration of heat penalty during the winter season are not clarified/considered in all studies.
- Not all studies account for impact of insulation thickness on energy efficiency.

Future Path by Publications

- The model can be used to measure cool roof effect on similar school building typologies (Stavrakakis et al., 2016)
- Further study is required to account for moisture transfer in the whole building to accurately determine the effect on energy performance (Saber et al., 2012)
- Additional investigation to consider future weather including climate change for different regions. Consideration of parameters like thermal emittance and roughness of roof membrane to evaluate their importance in affecting energy performance (Hosseini et al., 2017)
- Further research to understand how multiple cool roofs will impact local air temperatures and the impact of rooftop cooling on street level air temperatures (Virk et al., 2015)
- Development of roofing materials resistant to solar reflectance degradation (Parker, 2002)

Metal Roofs

Metal Roofs – Area and Type of Studies

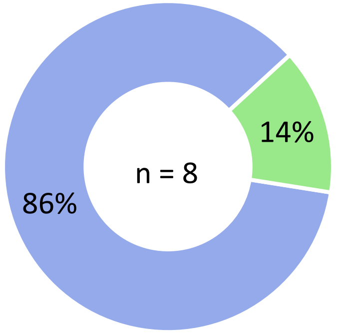


Sample size - 36

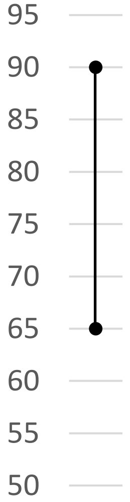
Total Area Studied – 172,623 SF
Average Area Studied – 6,165 SF

Total No. of Studies – 8
Simulation – 6
Real World - 2

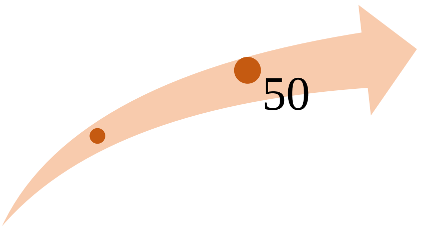
Types of Studies



White color roofs



Reflectance



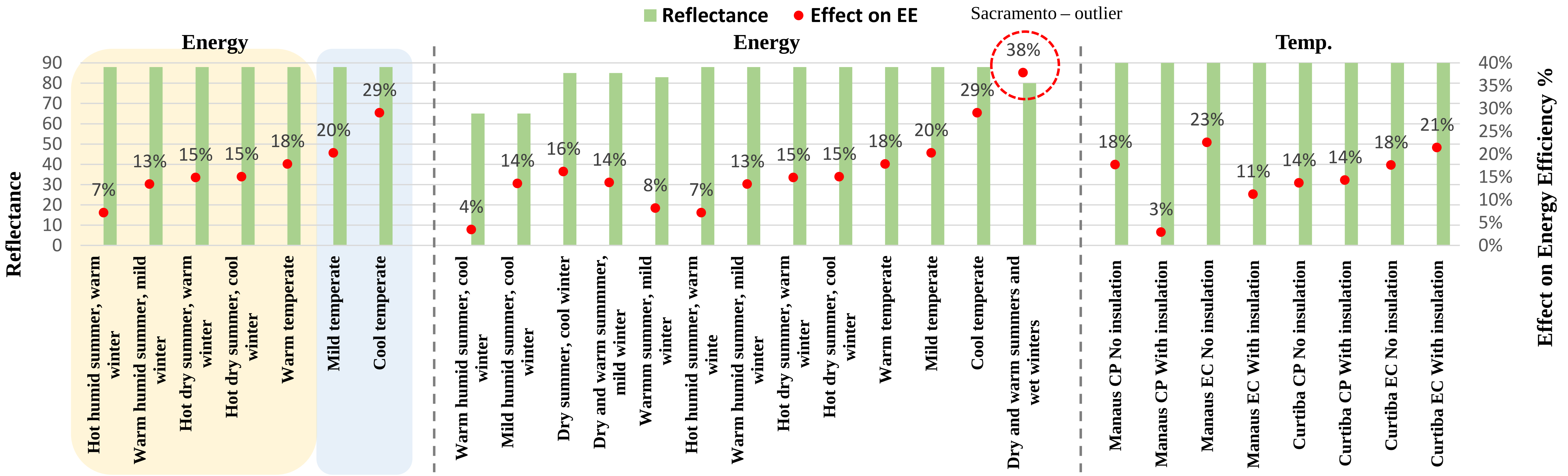
Insulation Thickness (mm)

Location, temperature range, month and duration of data capture

No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture
1	Bahrain	1	85 - 100	June	7
2	Darwin	2	68 - 93	Nov - Aug	270
3	Brisbane	2	53 - 82	Nov - Aug	270
4	Alice Springs	2	43 - 93	Nov - Aug	270
5	Dubbo	2	39 - 82	Nov - Aug	270
6	Sydney	2	48 - 74	Nov - Aug	270
7	Melbourne	6	46 - 72	January	4**
8	Canberra	2	34 - 74	Nov - Aug	270
9	Toronto	1	36 - 80	Nov - Aug	270
10	Montreal	1	32 - 77	Nov - Aug	270
11	Madrid	1	43 - 83	Nov - Aug	270
12	Barcelona	1	54 - 85	Nov - Aug	270
13	Bilbao	1	46 - 79	Nov - Aug	270
14	Sacramento	1	46 - 93	Nov - Aug	270
15	Manaus	4	75 - 92	Jan - Dec	0*
16	Curitiba	4	50 - 79	Jan - Dec	0*
17	California	1	52 - 74	May - Oct	190
18	Florida	1	62 - 90	July	7**
19	Ghana	1	76 - 89	Jan - June	150

*0 days assumed 365 days of analysis (all simulation-based)
**Real world studies
8 studies 36 sample size

Metal Roofs – Effect of Reflectance on Energy Efficiency



- Cool paint modification – different climate zones all over Australia
- Temperate and cold climates (blue) – less baseline case – more percentage savings but less energy consumption reduction.
- Warmer climates (yellow) – more base case – less percentage savings but more energy consumption reductions.

- Cool paint modification – different climate zones all over Australia, Canada, USA and Europe
- In colder climates, baseline value of energy consumption of standard roof is a low value which leads to higher % reductions but low energy consumption reduction.
- In warmer climates, baseline value of energy consumption of standard roof is a high value which leads to lower % reduction but higher energy consumption reduction..
- Inconsistent climate zones, locations, cool temperature vs hot temperature comparisons lead to confounding trends.

- Cool Paint and Elastomeric Coating with and without thermal insulation – different locations in Africa
- Higher percentage difference in external surface temperature with insulation in equatorial climates (Manaus) as against sub-tropical climate (Curitiba).
- The study has not looked at comparison with dark roof in sub-tropical climate zones.

Limitations and Future Path

By Publication

- The study is limited to a single building model and more work is required to establish the parameters to determine the benefit like cost investment and return on investment. The same process needs to be implemented for other commercial building types (Seifhashemi et al., 2018)
- The measurement period was limited to the month of September and October which are transitional cooling months and the results are limited to the measurement period only (Akbari et al., 1992)

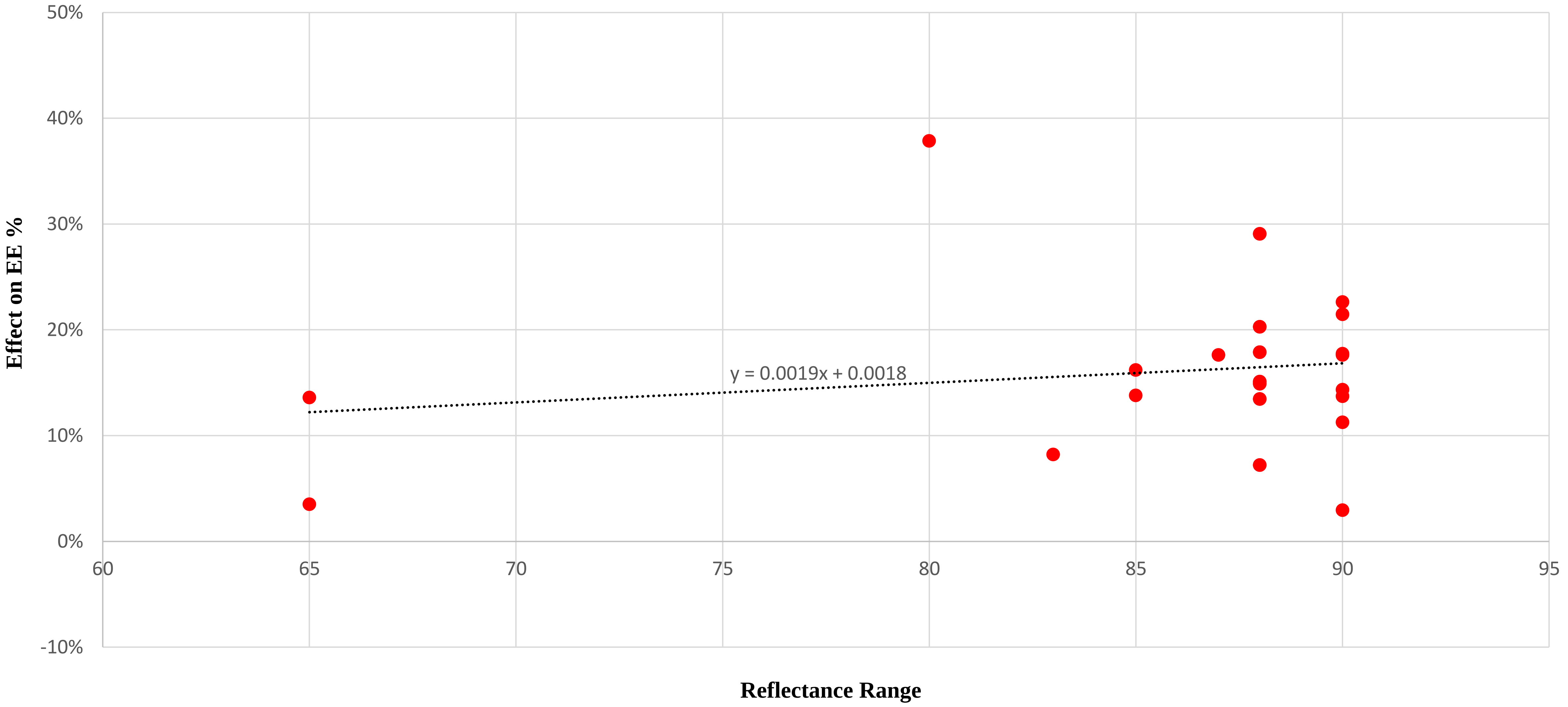
By Observation

- The climate zone and location of the study has an impact on the effect of cool roofs on energy efficiency.
- Studies focus mostly during summer months show higher energy savings and consideration of heat penalty during the winter season are not clarified/considered on all studies.
- Mostly simulation-based studies
- Majority of the studies utilize minimal data capture duration during specific months to draw conclusions for annual roof performance.
- Not all studies account for impact of insulation thickness on energy efficiency.

Future Path

- The role of cool roofs on all building types in a changing climate and the impact of changing climate on the effectiveness of cool roof coatings (Seifhashemiab et al., 2018)
- Cost benefit analysis for different climate zones (Filho et al., 2014)
- Study the climate-related heating interactions and development of roofing materials that are resistant to solar reflectance degradation. (Parker, 2002)

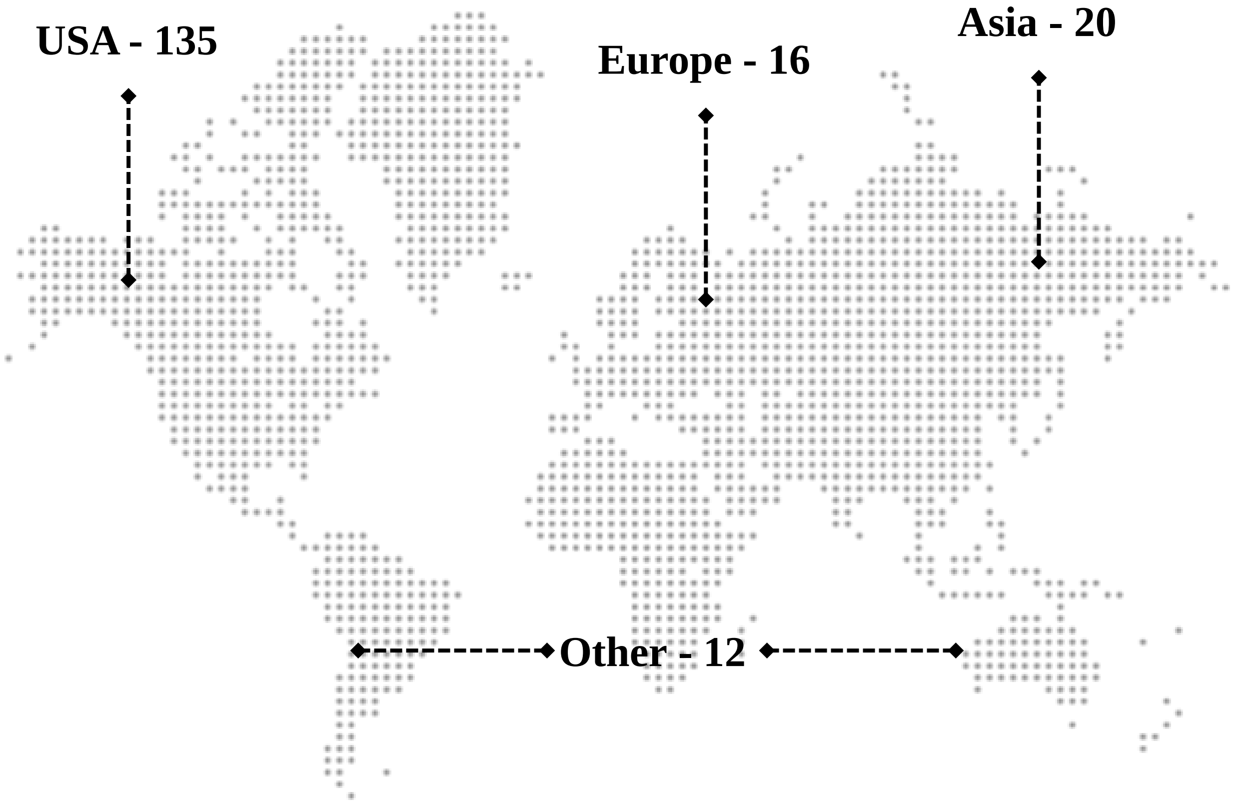
Metal Roofs – Effect of Reflectance on Energy Efficiency (All colors)



Insufficient data to draw conclusions.

TPO, EPDM and others

TPO, EPDM and others – Area and Type of Studies

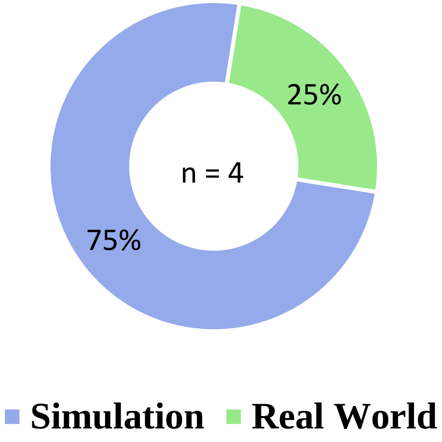


Sample size - 183

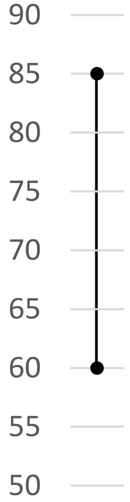
Total Area Studied – 141,240 SF
Average Area Studied – 35,310 SF

Total No. of Studies – 4
Simulation – 3
Real World – 1

Types of Studies



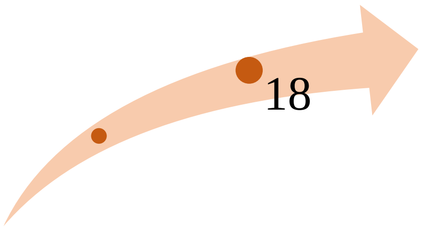
White color roofs in case study



Reflectance

Reflectance of TPO and EPDM membranes used in slide #37
White TPO Reflectance – 65.7
Black EPDM Reflectance – 6.5

Reflectance of TPO membranes used in slide #39
White Reflectance – 68
Tan Reflectance – 59
Gray Reflectance – 42



Insulation Thickness (mm)

Location, temperature range, month and duration of data capture

No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture
1	Albany	1	17 - 83	Jan - Dec	0*
2	Albuquerque	3	27 - 93	Jan - Dec	0*
3	Alexandria	1	29 - 88	Jan - Dec	0*
4	Athens	1	42 - 92	Jan - Dec	0***
5	Atlanta	6	35 - 89	Jan - Dec	0*
6	Austin	1	43 - 97	Jan - Dec	0***
7	Baltimore	6	30 - 89	Jan - Dec	0*
8	Boulder	3	22 - 87	Jan - Dec	0*
9	Charlotte	3	33 - 89	Jan - Dec	0*
10	Chicago	8	22 - 83	Jan - Dec	0***
11	Cocoa Beach	1	55 - 88	Jan - Dec	0***
12	Davis	1	39 - 93	Jan - Dec	0***
13	Duluth	3	7 - 78	Jan - Dec	0*

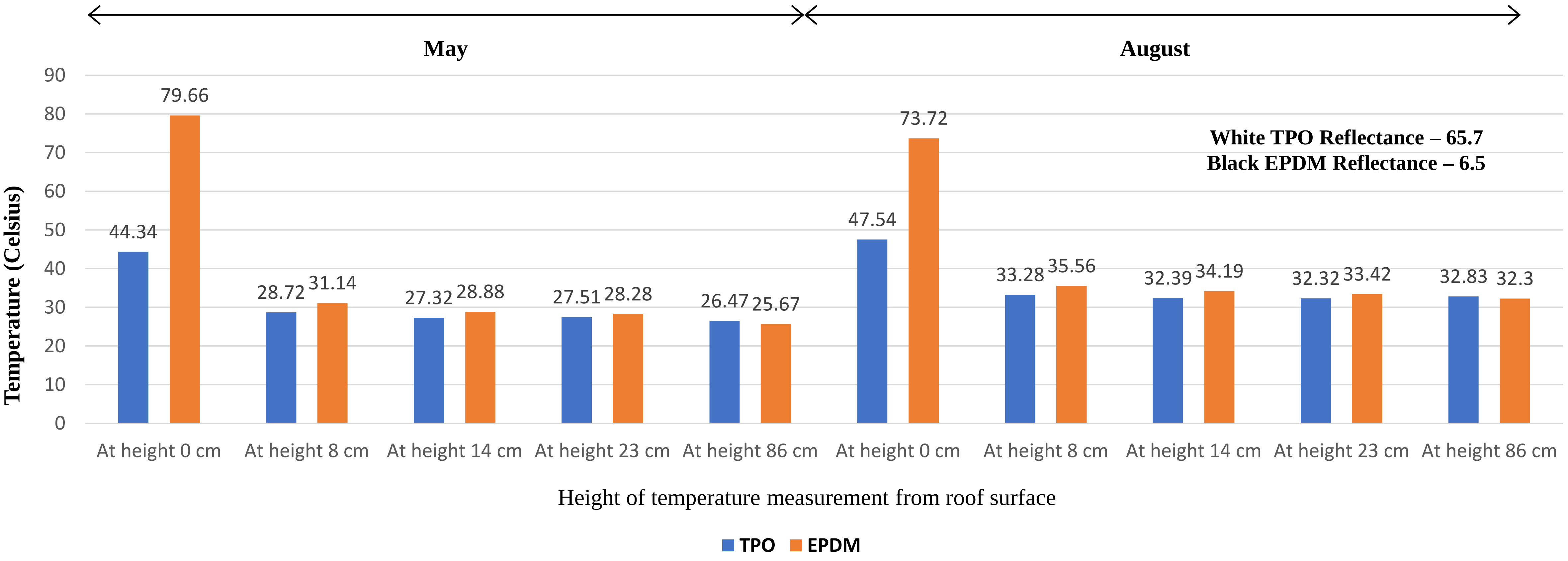
No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture
14	Fairbanks	3	-13 - 73	Jan - Dec	0*
15	Fort worth	3	37 - 97	Jan - Dec	0*
16	Fresno	3	39 - 99	Jan - Dec	0*
17	Gilroy	1	39 - 83	Jan - Dec	0***
18	Helena	3	13 - 86	Jan - Dec	0*
19	Houston	3	47 - 95	Jan - Dec	0*
20	Illinois	2	22- 83	Jan - Dec	0***
21	Jacksonville	3	46 - 90	Jan - Dec	0*
22	Las Vegas	3	38 - 105	Jan - Dec	0*
23	Los Angeles	3	48 - 85	Jan - Dec	0*
24	Miami	6	62 - 90	Jan - Dec	0*
25	Minneapolis	3	9 - 83	Jan - Dec	0*

No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture
26	Nashville	3	31 - 90	Jan - Dec	0*
27	New York	2	28 - 85	Jan - Dec	0***
28	Newark	3	26 – 86	Jan - Dec	0*
29	Phoenix	3	45 - 106	Jan - Dec	0*
30	Portland	6	36 - 84	Jan - Dec	0***
31	Sacramento	6	39 - 94	Jan - Dec	0***
32	San Francisco	3	45 - 72	Jan - Dec	0*
33	San Jose	1	43 - 82	Jan - Dec	0***
34	Scottsdale	3	44 - 106	Jan - Dec	0***
35	Seattle	3	37 - 79	Jan - Dec	0*
36	Virginia	20	29 - 89	May/Aug	2
37	Washington	2	29 - 88	Jan - Dec	0***

*Simulation based studies, the study provides energy savings for 365 days for unknown duration of data capture

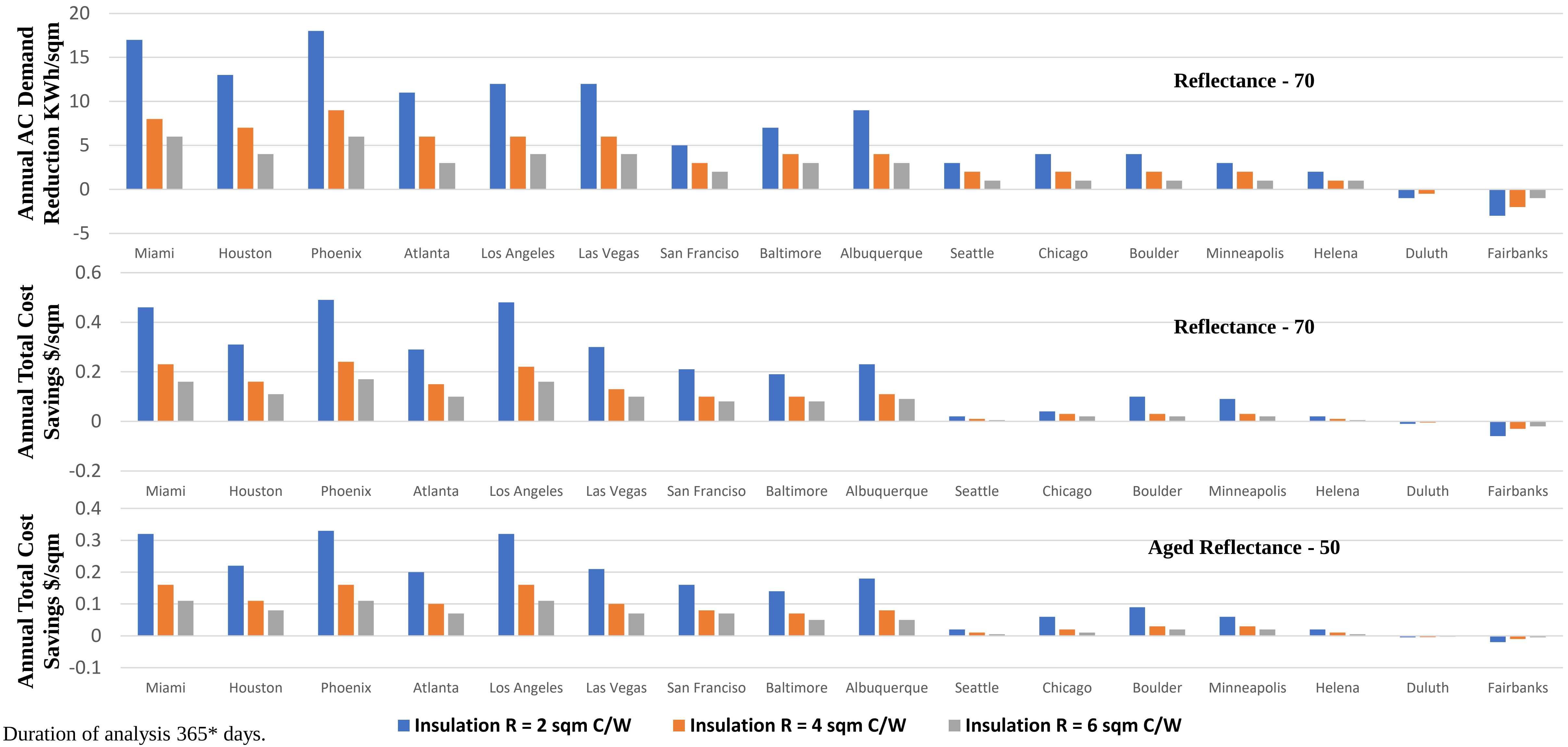
*** Simulation based studies, the study provides energy savings for 50 year LCCA for unknown duration of data capture

Measure of temperature from roof surface (White vs Black), [Grant et. al, 2017]



2 modifications on existing roof – Black EPDM and White TPO. The graph shows the temperatures of the membrane and air temperature at heights of 8, 14, 23 and 86 cms. above the roof surface. The study was carried out in Virginia during May and August.

Savings by varying insulation and reflectance [Tzempelikos et. al, 2021]

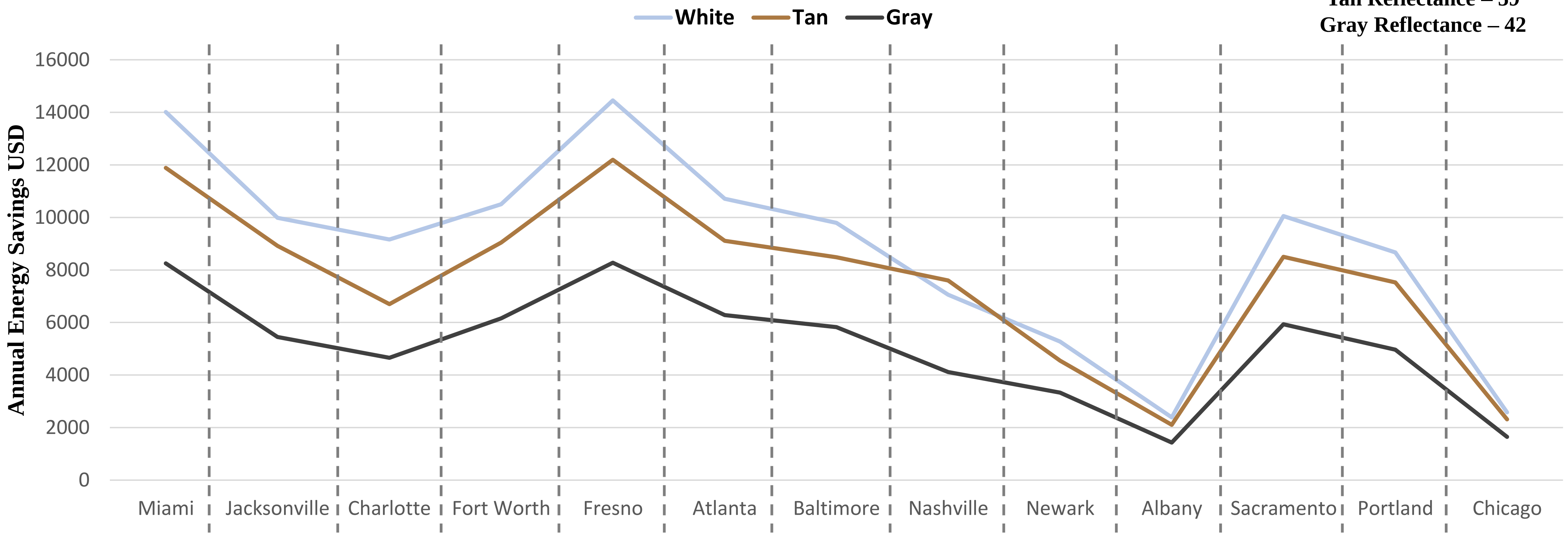


Duration of analysis 365* days.
* Simulation based study, not real world.

Savings by color of roof for different locations [Taylor et. al, 2019]

(White vs Tan vs Gray)

White Reflectance – 68
Tan Reflectance – 59
Gray Reflectance – 42



3 TPO membranes of 3 different colors – White with reflectance 68, Tan with reflectance 59 and Gray with reflectance 42 were used on a big box retail store in 13 locations over USA to calculate annual energy savings in USD. Duration 365* days.

- Simulation-based study, not real world.
- Electric Heating and Cooling

Economic comparison of white, green and black roofs [Sproul et. al, 2014]

Summary of 22 surveyed projects (key data and their medians).

#	Project	Location	Reroof	Year	Area (m^2)	First installation cost ($\$/m^2$)			Maintenance cost ($\$/m^2/year$)[$]			Heating savings relative to black ($\$/m^2/year$)			Cooling savings relative to black ($\$/m^2/year$)			Roof life (years)		
						G	W	B	G	W	B	G	W[#]	B	G	W	B	G	W	B
1	Buchanan R-Mer Lite	Illinois	New	2008	1988	172	99	22	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	25	30	20
2	Buchanan White PVC	Illinois	New	2008	1988	172	73	22	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	30	20	20
3	Chicago City Hall	Chicago, IL	New	2001	1886	215	22	129	2.9	0.2	0.2	0.7		0.0	0.3	0.2	0.0	40	20	20
4	Forrestal combined	Washington, DC	New		4644	226	31	22	0.5	1.1	0.2	0.7		0.0	0.4	0.4	0.0	30	20	20
5	Niu et al. (9 projects)	Washington, DC	N/A	2008	1794	210	22	242	2.9	0.2	0.2	0.0		0.0	0.3	0.2	0.0	40	20	20
6	Fieldston	New York, NY	N/A	2007	8779	183	22	75	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	30	20	20
7	Walmart Chicago	Chicago, IL	New	2006	6968	108	2.6	22	0.9	1.9	0.2	0.3		0.0	0.6	0.2	0.0	40	15	20
8	Jefferson School	Alexandria, VA	Reroof	1994	7711	172	42	22	2.9	0.2	0.2	0.3		0.0	0.3	4.0	0.0	40	20	20
9	Tanyard	Athens, GA	N/A	2002	929	155	22	84	2.9	0.2	0.2	0.3		0.0	0.4	0.2	0.0	40	20	20
10	Our Savior's	Cocoa Beach, FL	Reroof	1995	1115	172	5	22	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	40	20	20
11	Portland Building	Portland, OR	New	2008	3716	170	22	108	0.3	0.2	0.1	0.2		0.0	0.2	0.2	0.0	40	20	20
12	Hamilton Apt. Building	Portland, OR	Reroof	1999	780	164	22	22	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	40	20	20
13	Multnomah	Portland, OR	Reroof	2003	1115	162	22	108	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	40	20	20
14	Large Retail Store	Austin, TX	Reroof	2000	9290	172	16	16	2.9	0.2	0.2	0.3		0.0	0.3	0.6	0.0	40	13	13
15	Kaiser Permanente	Davis, CA	Reroof	1997	2945	172	22	22	2.9	0.2	0.2	0.3		0.0	0.3	0.7	0.0	40	20	20
16	Kaiser Permanente	Gilroy, CA	Reroof	1996	2211	172	22	22	2.9	0.2	0.2	0.3		0.0	0.3	0.4	0.0	40	20	20
17	Longs Drugs	San Jose, CA	Reroof	1997	3056	172	22	22	2.9	0.2	0.2	0.3		0.0	0.3	0.0	0.0	40	20	20
18	Sacramento Office	Sacramento, CA	Reroof	1996	2285	172	19	19	2.9	0.2	0.2	0.3		0.0	0.3	0.1	0.0	40	20	20
19	Sacramento Museum	Sacramento, CA	Reroof	1997	455	172	22	22	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	40	20	20
20	Sacramento Hospice	Sacramento, CA	Reroof	1997	557	172	14	13	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	40	20	20
21	Scottsdale Insurance	Scottsdale, AZ	New	2008	1059	172	86	22	2.9	0.2	0.2	0.3		0.0	0.3	0.2	0.0	40	20	20
22	Con Edison	New York, NY	New	2008	1000	172	22	22	2.9	0.2	0.2	0.3		0.0	0.2	0.1	0.0	40	20	20
				MEDIAN VALUE		172	22	22				0.3		0.0	0.3	0.2	0.0	40	20	20

Key: G, green; B, black, W, white; $, defaults from external sources rather than medians; #, no data on winter heating penalty for white.

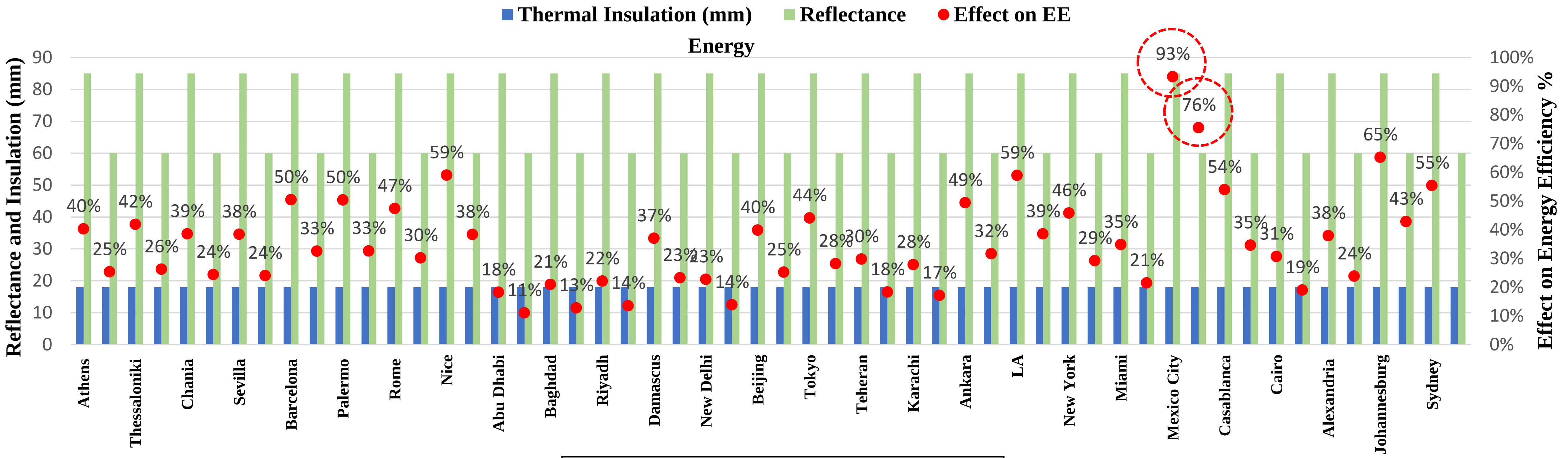
A study focused on life-cycle cost of green roof vs. dark roof vs. white roof with age of roof and maintenance cost as factors to evaluate heating / cooling savings by area per year

Case Study - Location, temperature range, month and duration of data capture [Synnefa et. al, 2007]

No.	Location	Number of Samples	Temperature Range (F)	Month study conducted	Duration of data capture	No.	Location	Number of Samples	Temperature Range (F)	Month study conducted	Duration of data capture
1	Athens	2	42 - 92	Jan - Dec	0*	15	Tokyo	2	36 - 87	Jan - Dec	0*
2	Thessaloniki	2	34 - 90	Jan - Dec	0*	16	Teheran	2	34 - 97	Jan - Dec	0*
3	Chania	2	47 - 88	Jan - Dec	0*	17	Karachi	2	55 - 94	Jan - Dec	0*
4	Sevilla	2	42 - 68	Jan - Dec	0*	18	Ankara	2	23 - 87	Jan - Dec	0*
5	Barcelona	2	40 -83	Jan - Dec	0*	19	LA	2	48 - 85	Jan - Dec	0*
6	Palermo	2	48 - 87	Jan - Dec	0*	20	New York	2	28 - 85	Jan - Dec	0*
7	Rome	2	37 - 89	Jan - Dec	0*	21	Miami	2	62 - 90	Jan - Dec	0*
8	Nice	2	41 - 82	Jan - Dec	0*	22	Mexico City	2	43 - 80	Jan - Dec	0*
9	Abu Dhabi	2	60 - 104	Jan - Dec	0*	23	Casablanca	2	49 - 79	Jan - Dec	0*
10	Baghdad	2	41 - 112	Jan - Dec	0*	24	Cairo	2	50 -96	Jan - Dec	0*
11	Riyadh	2	49 - 110	Jan - Dec	0*	25	Alexandria	2	29 - 88	Jan - Dec	0*
12	Damascus	2	34 -96	Jan - Dec	0*	26	Johannesburg	2	36 - 78	Jan - Dec	0*
13	New Delhi	2	46 -103	Jan - Dec	0*	27	Sydney	2	40 - 60	Jan - Dec	0*
14	Beijing	2	17 - 88	Jan - Dec	0*						

*Simulation based studies, duration of data analysis 365 days.
1 study 54 sample size

Effect of Reflectance and Insulation on Energy Efficiency [Synnefa et. al, 2007]



- This is 1 study, simulation based
- Same insulation thickness
- Two different levels of solar reflectance
- Global study in 27 cities
- No roof type mentioned – 100 sqm baseline case

There is lack of details on methodology to calculate baseline case. The study has an abnormal value for Mexico city (93% and 76% savings) as the baseline case was 9 kWh/sqm., whereas the range of baseline case for the rest of the 26 cities is 27.1 – 265.4 kWh/sqm and average is 77.22 kWh/sqm, the case for Mexico city is significantly lower than the lower range.

Limitations and Future Path

Limitations by Publications

- The lessons learned from the comparison show that the choice between cool, green and standard roofs is individual and depends on case to case. Factors like climate, rainfall, energy prices, stormwater management play a role in influencing the results of the comparison (Sproul et al., 2014)
- The building type is not representative of a typical building in all tested locations. The purpose of the study was to report cooling energy savings by changing the solar reflectance of the roof comparatively for various climatic conditions (Synnefa et al., 2007)

Limitations by Observation

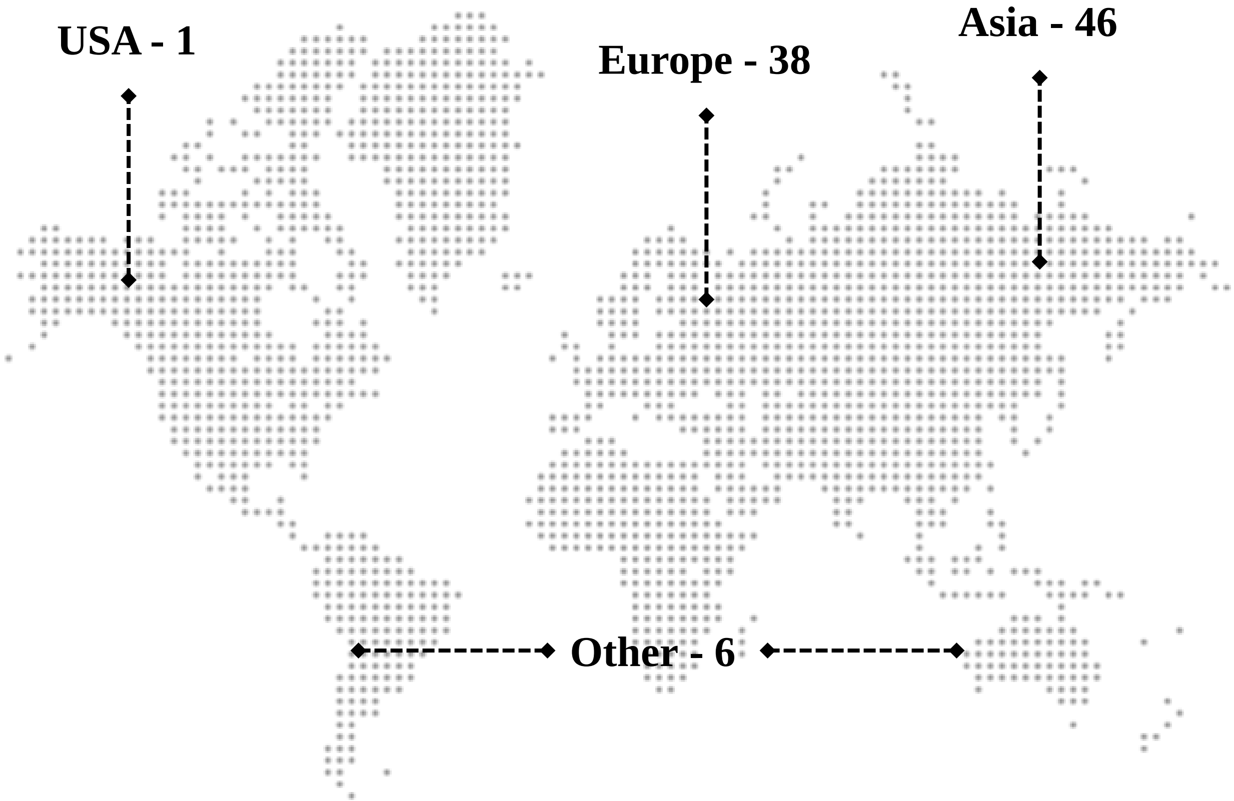
- All simulation-based studies
- Studies provide annual simulation-based analysis without clarifying the impact of different months/seasons
- A specific study provided the impact of cool roof on surface temperature without any correlation to the effect on energy efficiency
- Small sample size by climate zone, months and location.
- For better findings, study needs to be more focused by region

Future Path by Publication

- The study can promote the use of cool materials and the adoption of high albedo measures in building energy codes and urban planning regulations (Sproul et al., 2014)

Concrete Roofs

Concrete Roofs – Area and Type of Studies

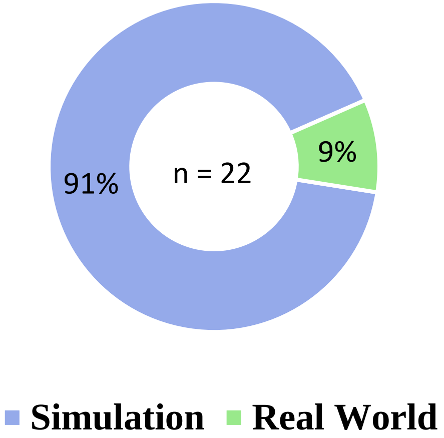


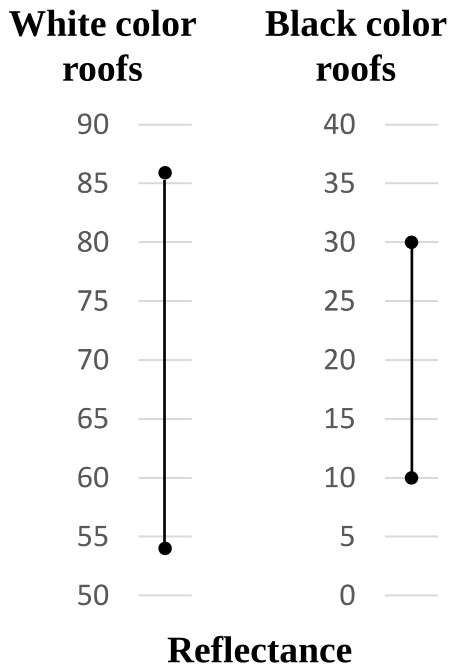
Sample size - 91

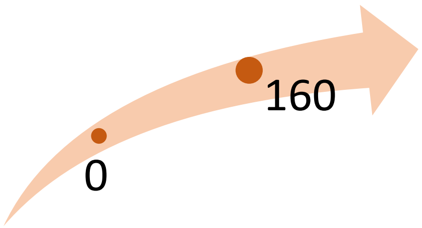
Total Area Studied – 265,498 SF
Average Area Studied – 3,540 SF

Total No. of Studies – 22
Simulation – 20
Real World – 2

Types of Studies







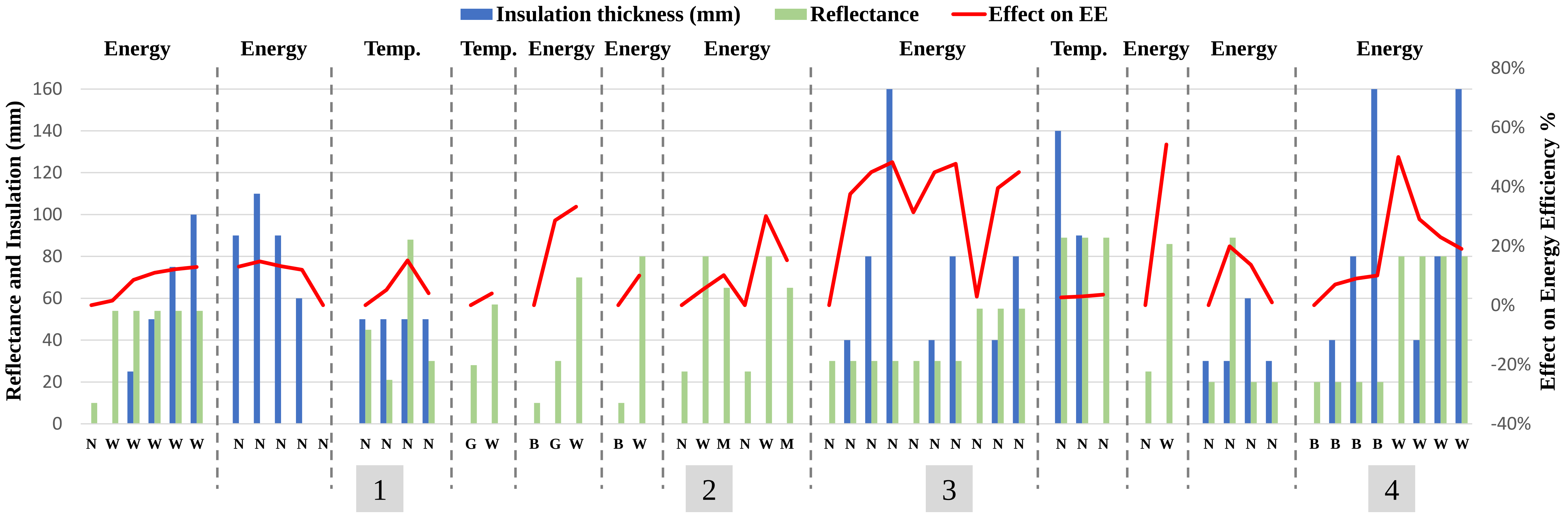
Insulation Thickness (mm)

Location, temperature range, month and duration of data capture

No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture	No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture
1	Ahmedabad	4	55 - 106	Jan - Dec	0*	13	Mumbai	4	66 - 92	Jan - Dec	0*
2	Bahrain	4	85 - 100	June	7	14	New Delhi	4	46 - 103	Jan - Dec	0*
3	Bangalore	4	61 - 93	Jan - Dec	0*	15	Osaka	6	58 - 76	May - Oct	180
4	Cairo	3	74 – 96	July	5	16	Palermo	4	74 - 87	July	5
5	Chongqing	2	77 - 93	August	1	17	Pantnagar	2	58 - 91	Jan - June	180**
6	Greece	4	72 - 90	July	15	18	Phoenix	1	75 - 105	Aug - Sept	40
7	Hyderabad	8	61 - 102	Jan - Dec	0*	19	Rome	1	55 - 85	Summer	1
8	Italy	22	65 - 85	April - Sept	30	20	Shillong	4	40 - 73	Jan - Dec	0*
9	Italy	2	55 - 85	Aug - Sept	12**	21	Sicily	2	60 - 80	May - Sept	110
10	Jamaica	1	73 - 89	Jan - Dec	0*	22	Singapore	4	76 - 89	Jan - Dec	0*
11	London	2	46 - 66	May - Sept	150	23	Turin	1	31 - 84	Summer	1
12	Melbourne	2	60 - 79	January	3						

*0 days assumed 365 days of analysis (all simulation-based)
**Real world studies
22 studies 91 sample size

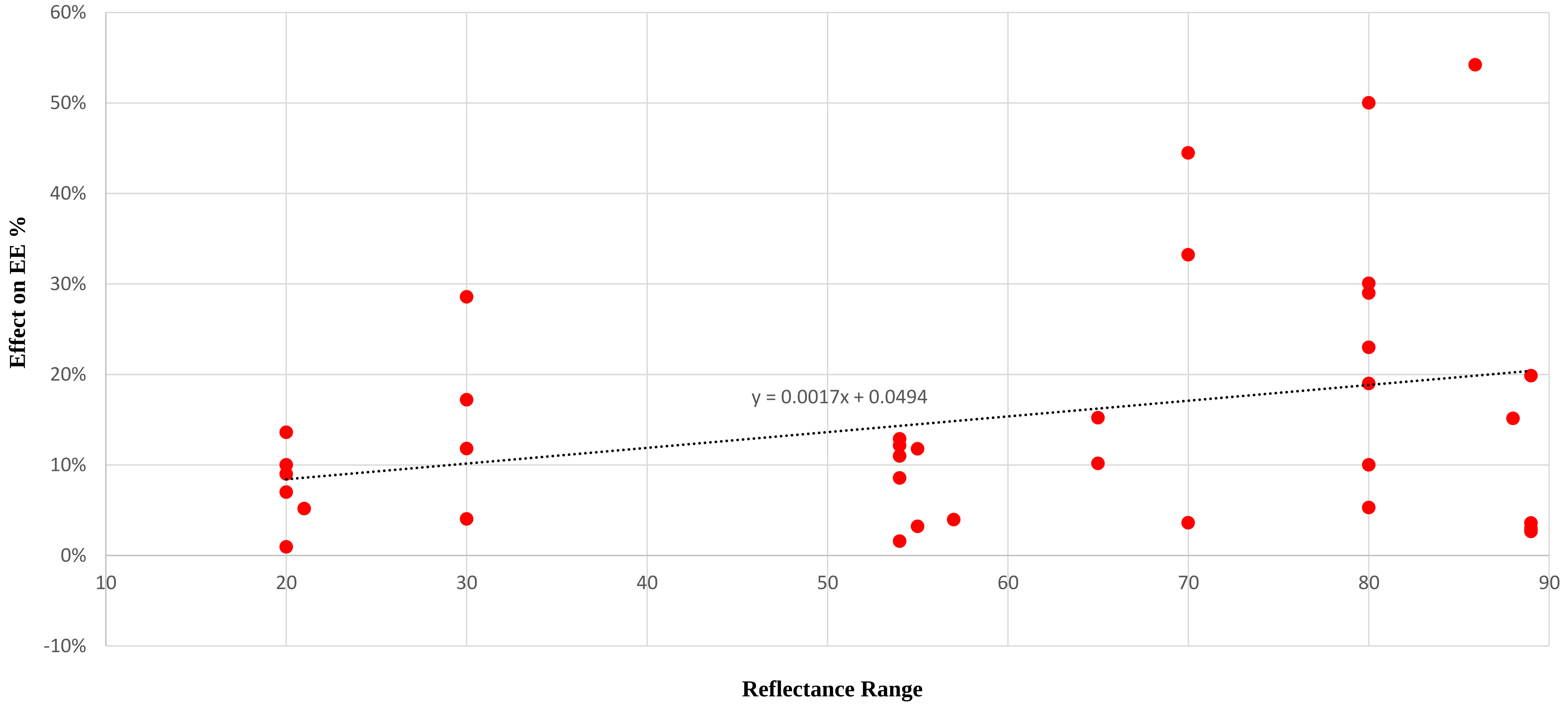
Concrete Roofs – Effect of Reflectance and Insulation on Energy Efficiency (All colors)



1	4 modifications - lightweight concrete screed, bituminous roofing felt, light and dark colored tile. Insulation kept constant, light tile - maximum reflectance - maximum energy efficiency.
2	3 modification – standard concrete roof vs white color cool paint roof vs metallic reflective coating roof. Cool paint shows maximum energy efficiency.
3	3 modifications – 4 standard roof, 3 green roof and 3 cool roof. Increase in insulation thickness increases energy efficiency.
4	8 modifications – Black reflectance 20 and white reflectance 80 with 4 insulation thicknesses. White with 0 insulation gives maximum energy efficiency as study is done in April.

N – Roof color not mentioned   W – White color roof   G – Gray color roof B – Brown color roof M – Metallic reflective coating

Concrete Roofs – Effect of Reflectance on Energy Efficiency



Limitations and Future Path

Limitations by Publications

- Application of cool roofs leads to a decreased comfort in winter months but the benefits from the summer months lead to a net increase in comfort (Arumugam et al., 2014)
- The building prototypes are typical of the location and represent savings for a specific building computed (Gao et al., 2014)
- The study did not account for ageing, soiling and weatherability of the cool material during the life span of the building (Romeo et al., 2013)

Limitations by Observation

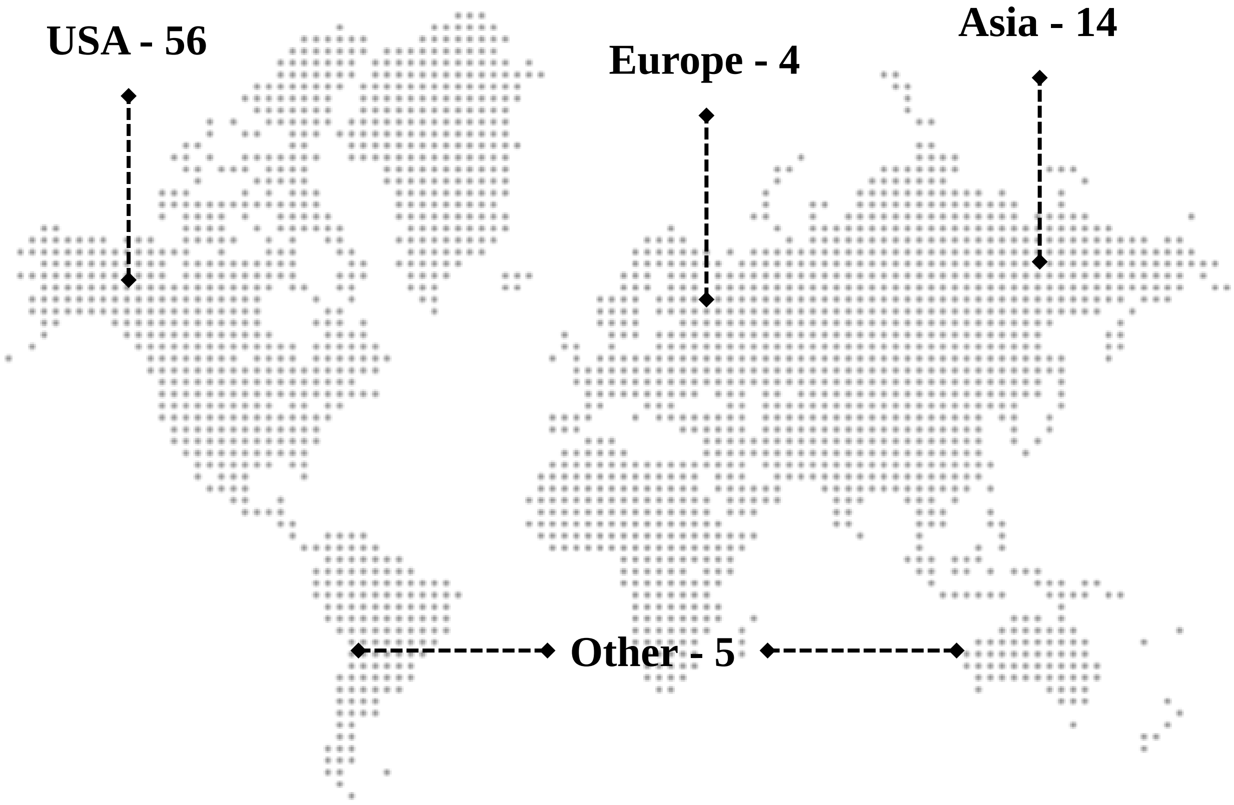
- Studies must consider the effect of thermal insulation thickness which plays a critical role in reducing heat gains in hotter climates and minimizing heat energy loss in colder climates.
- Mostly simulation-based studies
- Studies focus mostly during summer months show higher energy savings and consideration of heat penalty during the winter season are not clarified/considered on all studies.
- Majority of the studies utilize minimal data capture duration during specific months to draw conclusions for annual roof performance.
- Multiple variables in the studies have been changed simultaneously resulting in confounding findings

Future Path by Publications

- Further study can include the increase in occupant comfort with the use of cool roofs and the amount by which soiling degrades the albedo of cool roofs. Yafeng Gao et al. (2014)
- Cost benefit analysis of the implementation of cool roofs. Elisa Di Giuseppe et al. (2017)
- Evaluating the benefits of widespread use of cool roof technology throughout the region including the impact on urban heat island effect and environmental impact. J.H. Jo et al. (2009)

Asphalt Shingles

Asphalt Shingles – Area and Type of Studies

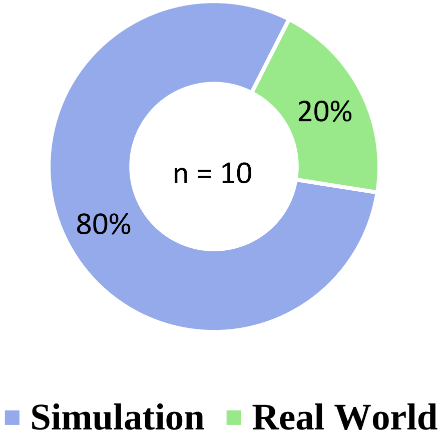


Sample size - 79

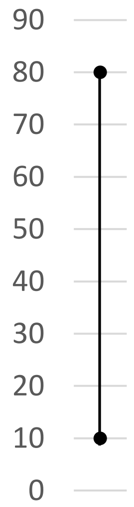
Total Area studied – 213,910 SF
Average Area studied – 3,395 SF

Total No. of Studies – 10
Simulation – 8
Real World - 2

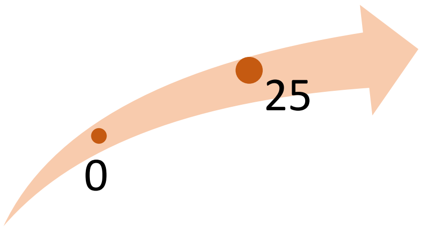
Types of Studies



White color roofs



Reflectance



Insulation Thickness (mm)

Location, temperature range, month and duration of data capture

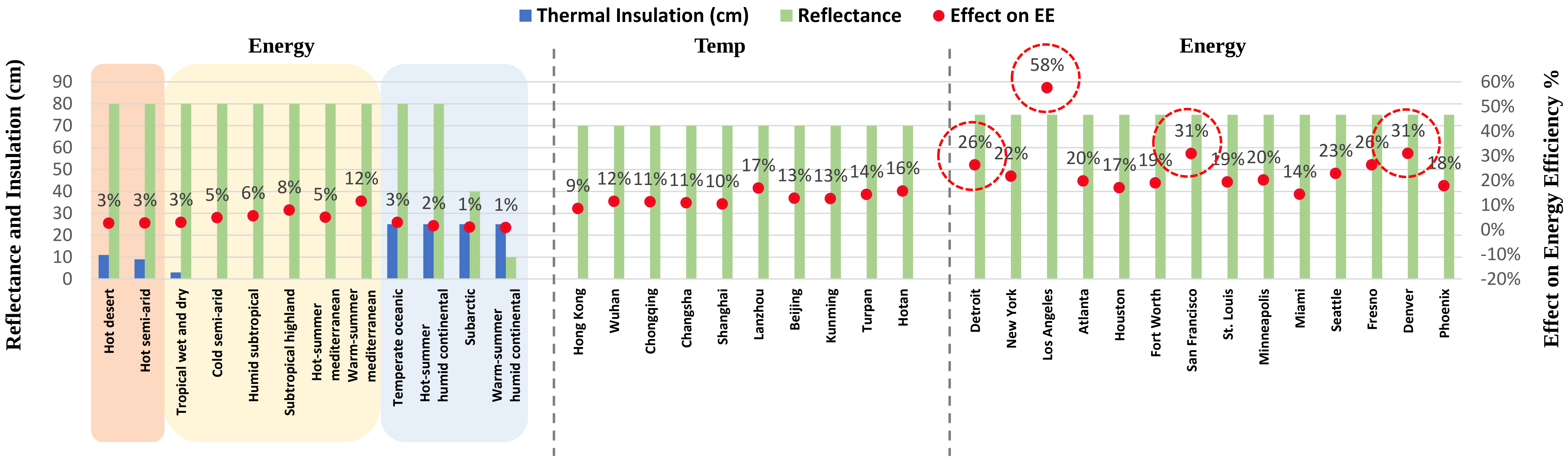
No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture	No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture	No.	Location	Sample Size	Temperature Range (F)	Month study conducted	Duration of data capture
1	Abu Dhabi	1	60 - 104	Jan - Dec	0*	16	Chongqing	1	44 - 94	Jan - Dec	0*	31	Miami	3	77 - 88	Jun - Aug	90
2	New Delhi	1	46 - 103	Jan - Dec	0*	17	Dallas	2	39 - 96	Jan - Dec	0*	32	Minneapolis	1	59 - 80	Jun - Aug	90
3	Rio de Janeiro	1	65 - 88	Jan - Dec	0*	18	Davis	1	54 - 89	Jun - Sept	120**	33	New Orleans	2	47 - 92	Jan - Dec	0*
4	Thessaloniki	1	34 - 90	Jan - Dec	0*	19	Denver	1	55 - 90	Jun - Aug	90	34	New York	3	64 - 84	Jun - Aug	90
5	Sydney	1	40 - 60	Jan - Dec	0*	20	Detroit	1	60 - 80	Jun - Aug	90	35	Philadelphia	2	26 - 87	Jan - Dec	0*
6	Mexico City	1	43 - 80	Jan - Dec	0*	21	Florida	12	78 - 88	Jul - Aug	7**	36	Phoenix	3	76 - 105	Jun - Aug	90
7	San Francisco	2	45 - 72	Jan - Dec	0*	22	Fortsworth	1	73 - 98	Jun - Aug	90	37	Rome	1	37 - 89	Jan - Dec	0*
8	Paris	1	46 - 77	Jan - Dec	0*	23	Fresno	1	62 - 97	Jun - Aug	90	38	San Jose	1	56 - 81	Jun - Sept	120**
9	Beijing	2	17 - 88	Jan - Dec	0*	24	Gilroy	1	52 - 86	Jun - Sept	120**	39	Seattle	1	54 - 72	Jun - Aug	90
10	Tampere	1	13 - 71	Jan - Dec	0*	25	Hong Kong	1	57 - 89	Jan - Dec	0*	40	Shanghai	1	35 - 90	Jan - Dec	0*
11	Moscow	1	12 - 76	Jan - Dec	0*	26	Hotan	1	18 - 89	Jan - Dec	0*	41	St. Louis	1	67 - 88	Jun - Aug	90
12	Atlanta	3	65 - 88	Jun - Aug	90	27	Houston	3	74 - 91	Jun - Aug	90	42	Toronto	3	17 - 78	Oct - Apr	210
13	California	3	66 - 84	May - Oct	180	28	Kunming	1	37 - 75	Jan - Dec	0*	43	Turpan	1	14 - 103	Jan - Dec	0*
14	Changsha	1	36 - 91	Jan - Dec	0*	29	Los Angeles	3	62 - 85	Jun - Aug	90	44	Washington	2	29 - 88	Jan - Dec	0*
15	Chicago	2	22 - 83	Jan - Dec	0*	30	Lanzhou	1	11 - 83	Jan - Dec	0*	45	Wuhan	1	34 - 91	Jan - Dec	0*

*0 days assumed 365 days of analysis (all simulation-based)

**Real world studies

10 studies 79 sample size

Asphalt Shingles – Effect of Reflectance and Insulation on Energy Efficiency

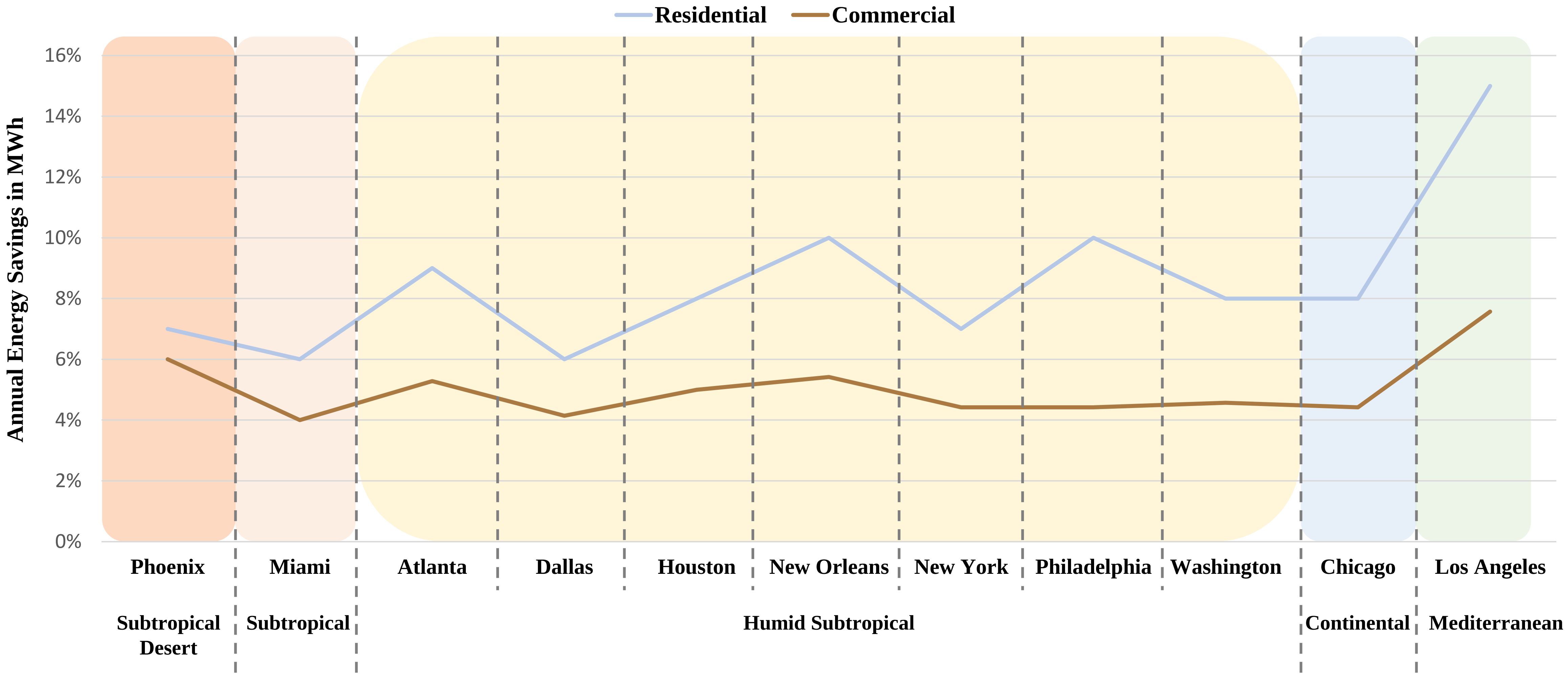


- Study tries to define optimum level of insulation and solar reflectance for various climate zones.
- White roof -varied insulation thickness and solar reflectance
- 12 different cities over the world with varied climate zones
- Hot (orange) – 9-11 cms of insulation to reduce energy consumption
- Warm (yellow) – negligible insulation is optimum
- Cold (blue) – 25 cms of insulation to minimize heating demand

- Impact of roof reflectance change from 10 to 70 identified from the chart from 9-17% by 10 locations in China.

- White roof modification in 14 cities in USA
- Average of baseline case is 2.8 kWh/sqf for 10 cities apart from the outliers Detroit (26%), Los Angeles (58%), San Francisco (31%), Denver (31%).
- Average of the base case for 4 outliers is 0.6 kWh/sqf which is significantly lower than 2.8 kWh/sqf.
- A small change in lower baseline value creates more % savings but less energy consumption reduction in comparison to a larger baseline value.

Asphalt Shingles – Effect of Albedo on Energy Efficiency [Akbari et. al, 1999]



- Simulation based study – study the effect of modification of roof albedo from 0.25 to 0.55 with the use of cool white paint in 11 cities in USA
- Annual energy % savings increase as climate gets colder
- In colder climates, baseline value of energy consumption of roof with 0.25 albedo is a low value which leads to higher % reductions but low energy consumption reduction.

Limitations and Future Path

By Publication

- Dark roofs increase the opportunity for savings and another factor that affects the monetary savings is the local cost of electricity. High cost of electricity causes more dollar savings in that city (Akbari et al., 1999)
- The measurement period was limited to the month of September and October which are transitional cooling months and the results are limited to the measurement period only (Akbari et al., 1999)
- The effect of lightening the color of the roof on heating energy savings is nil because in the winters, the roof gets covered in snow (Akbari et al., 1999)

By Observation

- Mostly simulation-based studies
- Studies comparing energy cost savings by different locations without normalizing the energy cost for that region will not produce meaningful comparisons
- Studies focus mostly during summer months show higher energy savings and consideration of heat penalty during the winter season are not clarified/considered on all studies.
- Majority of the studies utilize minimal data capture duration during specific months to draw conclusions for annual roof performance.

Future Path

- Implementation programs for white roofs should be designed to emphasize the roof types that cover the largest area in the city. Built-up roofs and modified bitumen can be coated with white reflective coating with a little installation cost. For asphalt shingles, it is an additional expense and is not covered in installation, voids the warranty, it is necessary to induce shingle manufacturers to sell high-albedo shingles which shed dirt (Rosenfeld et al., 1995)
- Investigation of the economic and life cycle benefits of installing cool roofs in varying climatic conditions (Piselli et al., 2019)
- Development of roofing materials resistant to solar reflectance degradation (Parker, 2002)

Conclusions* - Effect of Membrane Color on Energy Efficiency

	BUILT UP	ASPHALT SHINGLES	TPO, EPDM, PVC	METAL	CONCRETE
REFLECTANCE	Solar reflectance plays an important role in the effect of cooling demand	Roof thermal insulation with cool roof does not allow dissipation of internal heat gains, thus increasing cooling demand for building in “Hot & Mild Climate” zones	Increased levels of reflectivity increase the amount of annual energy savings.	Cool Roofs with high reflectivity in equatorial climates are effective in contrast to sub-tropical climates (reversing the direction of heat flux)	A white coated roof with no insulation gives maximum energy efficiency. AND As albedo increases energy efficiency increases.
ENERGY SAVINGS	Temperature variation with a lower baseline value represents higher % savings in comparison to a higher baseline value	A small change in lower baseline value creates more % savings but less energy consumption reduction in comparison to a larger baseline value	Roofing life cycles are normally measured in terms of decades and therefore an entire Life-Cycle Analysis is essential to evaluate energy efficiency.	For temperate and cold climates with less baseline case more percentage savings but less energy consumption reduction.	A combination of highly reflective roofing and thermal insulation is more effective in reducing the thermal load as compared to reflective roofing or insulation alone
	% reduction in temperature as a result of a change in the roofing membrane color leads to inconsistent results				The heating load decreased as the insulation thickness increased from 25mm to 100 mm.
INSULATION	Insulation in roofing membrane increases the energy efficiency	Roof thermal insulation plays an important role in extreme climatic conditions especially “Cold Climates”	Roof insulation is critical for all climates. The impact of roof reflectivity is equally important for warm climates.	Higher percentage difference in external surface temperature with insulation in equatorial climates (Manaus) as against sub-tropical climate (Curitiba).	Cool paint with the same insulation as the baseline case exhibits higher energy efficiency.
	Insulation plays a significant role in the effect of roofing membrane on heating demand	Energy efficiency of a building is more sensitive to roof solar reflectance than thermal insulation, except for cold climate zone	Annual energy savings achieved in all cities expect for cities in cold climate zone	Insulation increases the external surface temperature of the roof.	Insulation is not needed with cool roofs in all climatic zones except cold climates

** Conclusions by observation and analysis require an in-depth data analysis through experimental/empirical study to validate results*

Gaps in Study of Effect of Membrane Color for Energy Efficiency

- Optimal design for the study of the effect of the color of the membrane in roof design for energy efficiency is needed
- Studies that focus on the impact of changing climate on the energy efficiency in relation to different roof modifications (different color, product type, insulation, etc.) is needed.
- Life-cycle analysis for calculation of energy savings in terms of dollar value is needed over the life of a roof (cost-benefit analysis)
- The evaluation of optimal ratio of cold vs. warm months on annual energy efficiency as a result of different roof modifications (different color, product type, insulation, etc.) is needed.
- Studies did not account for aging, soiling, and weatherability of the cool material during the life span of the building
- Impact on local air temperatures and the impact of rooftop cooling on street-level air temperatures by multiple cool roofs is yet to be evaluated
- Detailed experimental and simulation analyses need to be performed for cold and continental climatic conditions to investigate their thermal output and also the relevant compensation strategies to outperform this negative output need to be developed.
- Increase in occupant comfort with the application of cool roof and altering the albedo value is needed.

Manufacturers

Framework to document manufacturer claims

01
Identifying Manufacturers

Types of roof and Claims

- 17 Manufacturers were identified
- Roof Types (Single-Ply and Multi-Ply) were searched

02
Manufacturer Websites

Searching the Website and brochures

- Brochures were studied
- Website were searched for roof types

03
Claims

Finding Sustainability Claims

All claims were studied and relevant claims to sustainability were selected

04
Certification

Finding basis for claims

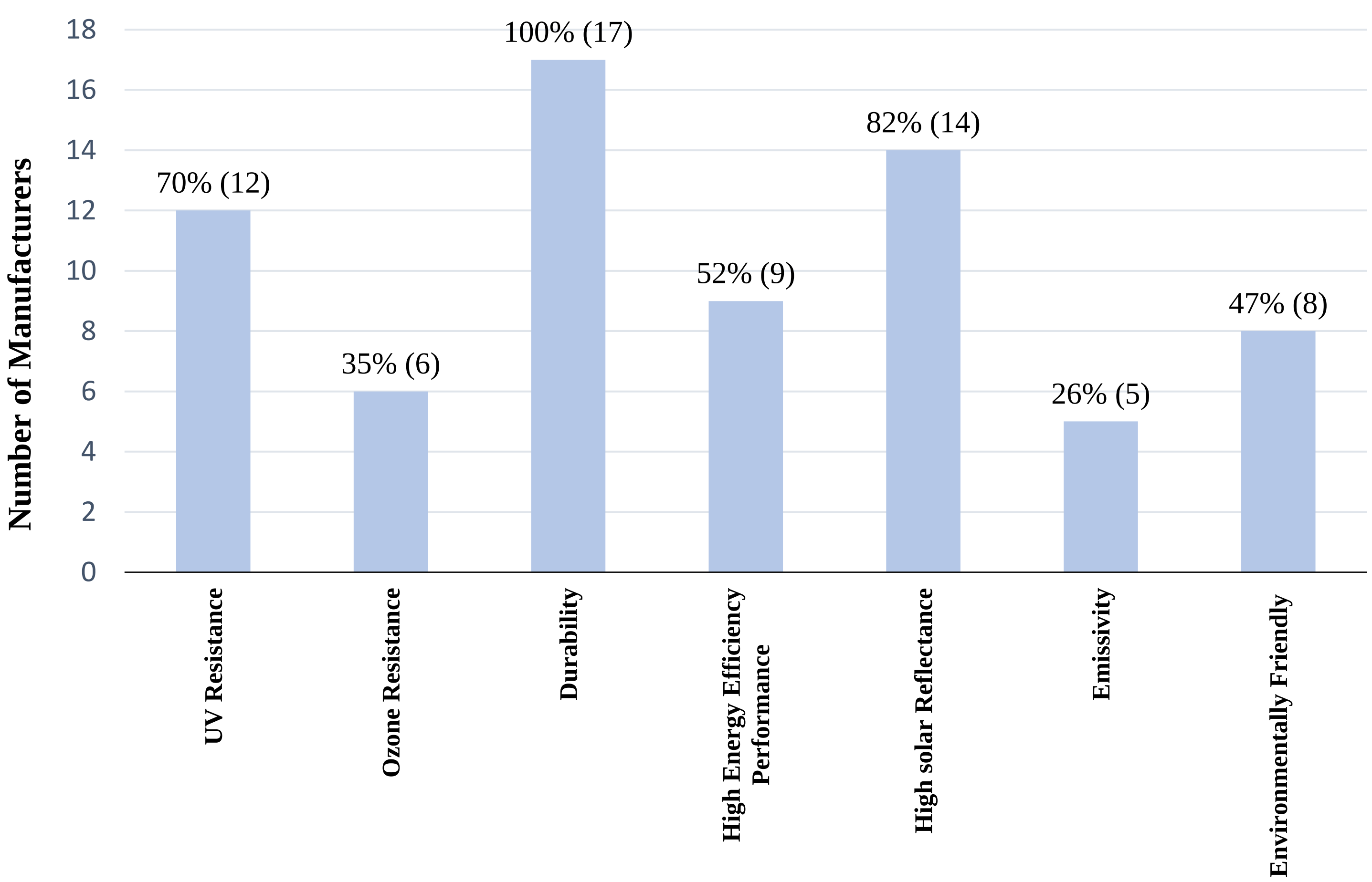
- Internal or external Claims
- Some claims were based on Certification and Standards

Manufacturer's roof products

Manufacturers*	TPO	PVC	EPDM	Bituminous
A*	✓	×	✓	×
B*	✓	✓	✓	×
C*	✓	✓	✓	×
D*	✓	×	✓	×
E*	×	×	×	✓
F*	×	×	×	✓
G*	×	✓	×	✓
H*	×	×	×	×
I*	×	×	×	×
J*	×	✓	×	×
K*	×	×	×	×
L*	×	✓	×	×
M*	✓	×	×	×
N*	✓	✓	×	✓
O*	✓	×	✓	×
P*	✓	✓	✓	×
Q*	✓	×	✓	×

*For privacy, the name of manufacturers is not mentioned

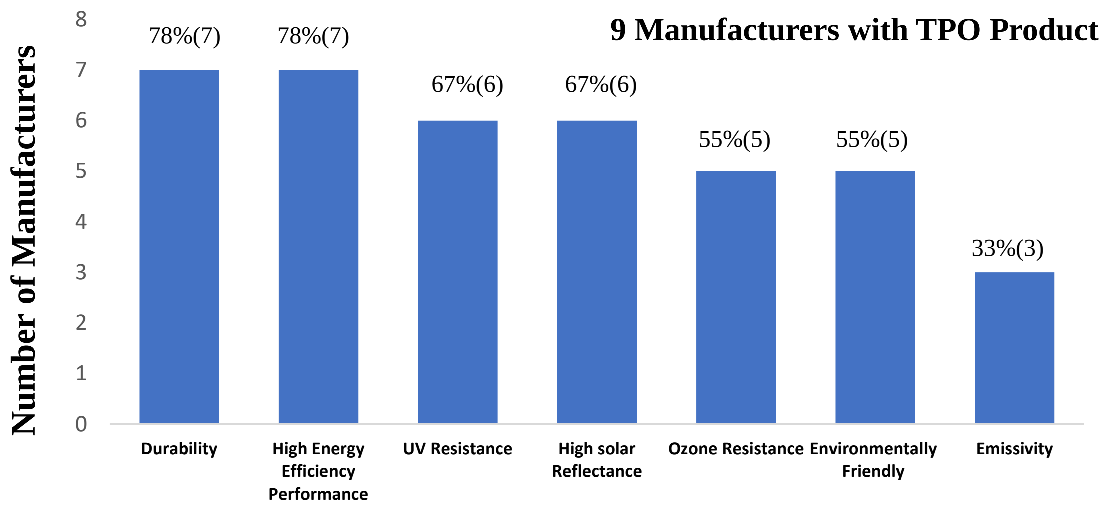
Number of manufacturers and claims

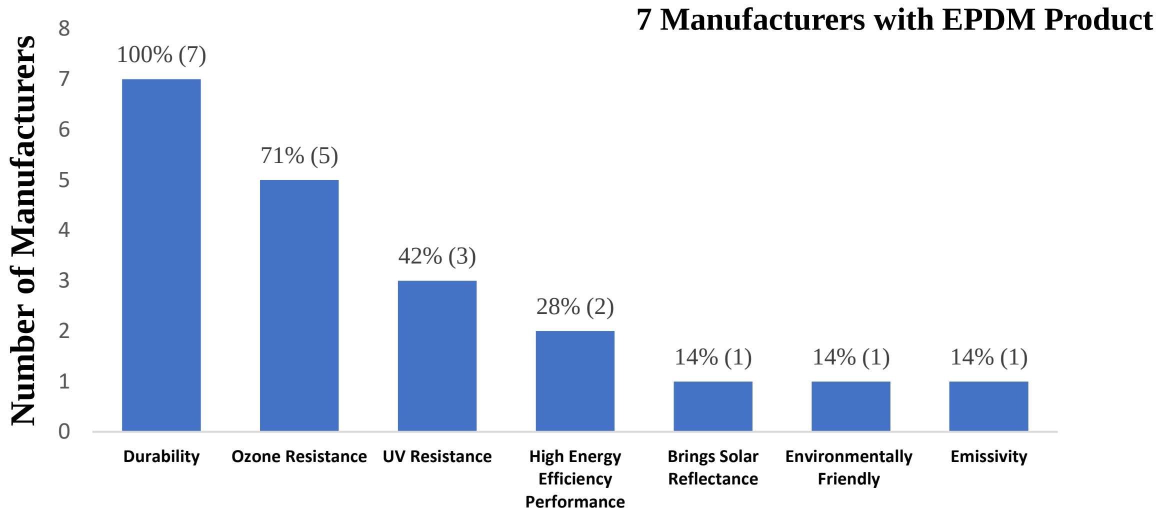


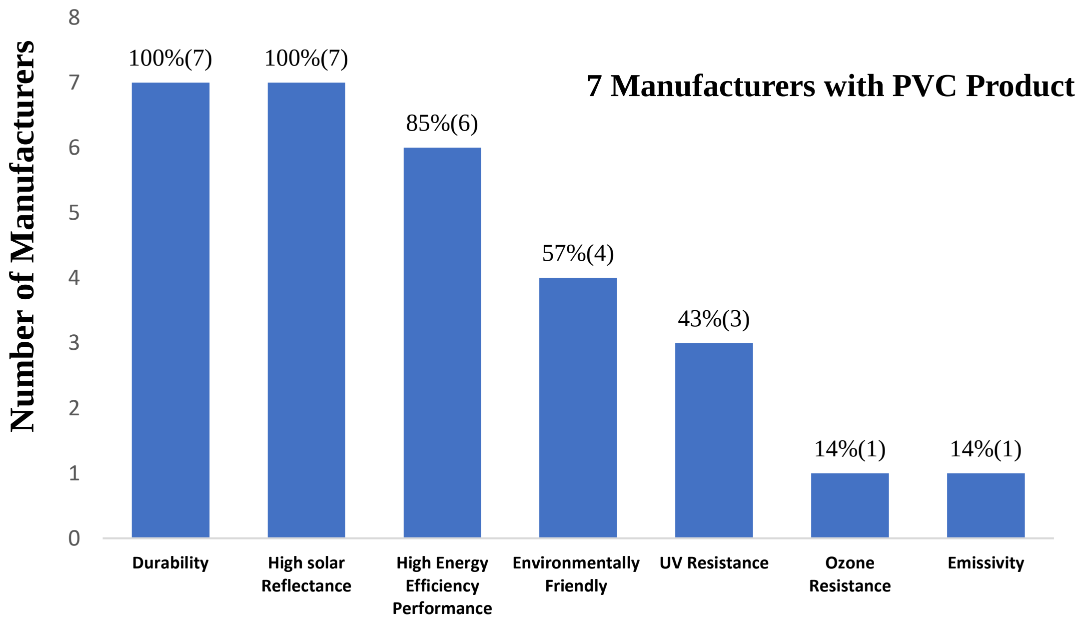
Claims used by 17 Manufacturers

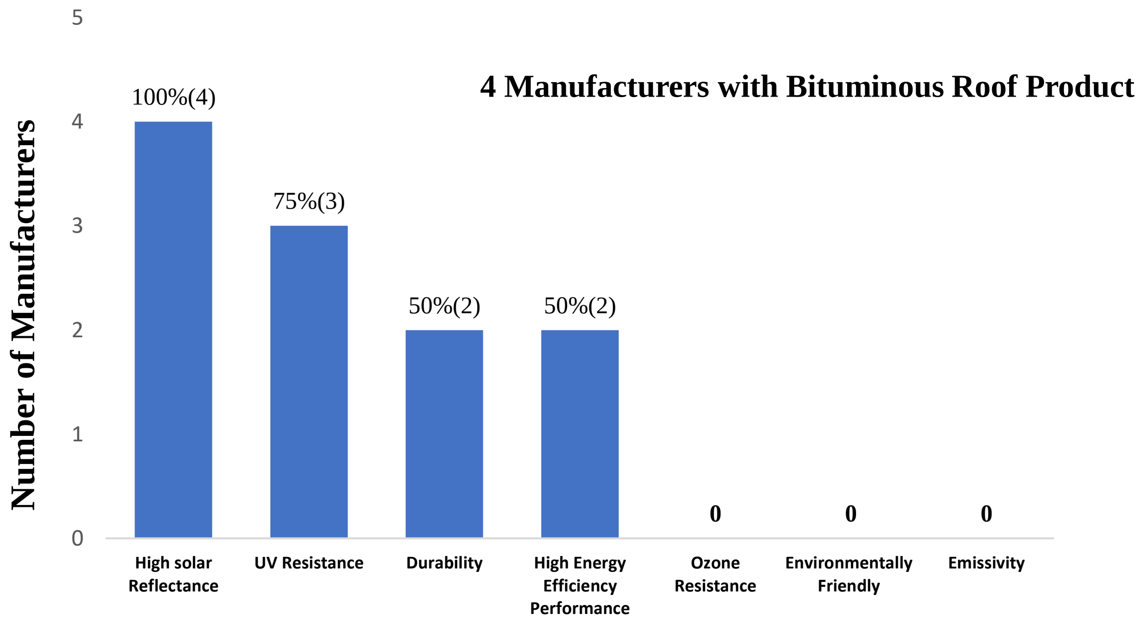
Claim	TPO	PVC	EPDM	Bituminous
UV Resistance	✓	✓	✓	✓
Ozone Resistance	✓	✓	✓	×
Durability	✓	✓	✓	✓
High Energy Efficiency Performance	✓	✓	✓	✓
High Solar Reflectance	✓	✓	✓	✓
Emissivity	✓	✓	✓	×
Environmentally Friendly	✓	✓	✓	×

Manufacturers Claims by Roof Type









Claims based on Standards/Certifications

Standards	UV Resistance	Ozone Resistance	Durability	High Energy Efficiency Performance	High Solar Reflectance	Emissivity	Environmentally Friendly
CRRC	×	×	×	×	✓	✓	×
Energy Star	×	×	×	✓	✓	×	×
California Title 24	×	×	×	✓	✓	✓	×
LEED	×	×	×	✓	✓	×	✓
ISO 9001:2015	×	×	✓	×	×	×	×
ASTM D4601	×	×	✓	×	×	×	×
ASTM D2178	×	×	✓	×	×	×	×
FM Standard 4470.	×	×	✓	×	✓	×	×
ASTM D 622	×	×	✓	×	×	×	×
ASTM D 6164	×	×	✓	×	×	×	×
ASTM D570	×	×	×	×	×	×	×
ASTM G154	✓	×	✓	×	×	×	×
ASTM C1549	×	×	×	×	✓	×	×
ASTM C1371	×	×	×	×	×	✓	×
ASTM D4434	×	×	✓	×	×	×	×
ASTM D4637	×	×	✓	×	×	×	×
ASTM D6878	×	×	✓	×	×	×	×

Standards used by different roof types

Standards	TPO	PVC	EPDM	Bituminous Roof	Definition
CRRC	✓	✓	×	×	Solar Reflectance and Emissivity
Energy Star	✓	✓	×	×	Energy Efficiency, Solar Reflectance And Emissivity
California Title 24	✓	✓	×	×	Energy Efficiency, Solar Reflectance And Emissivity
LEED	✓	✓	×	×	Energy Efficiency And Emissivity, Environmentally Friendly
ISO 9001:2015	×	×	×	✓	Effective Application Of The Roofing System
ASTM D4601	×	×	×	✓	Crack Resistant
ASTM D2178	×	×	×	✓	Waterproofing
FM Standard 4470	×	×	×	✓	Water-leakage, Corrosion Of Metal Parts
ASTM D 622	×	×	×	✓	Waterproofing
ASTM D 6164	×	×	×	✓	Waterproofing (Ultimate Elongation, Tear Strength, Low Temperature Flexibility, And Dimensional Stability)
ASTM D570	×	✓	×	×	Water Absorption Of Plastic
ASTM G154	×	✓	×	×	UV Resistance Test
ASTM C1549	×	×	✓	×	Solar Reflectance
ASTM C1371	×	×	✓	×	Emissivity
ASTM D4434	×	✓	×	×	Fire Resistance And, Wind Uplift Resistance
ASTM D4637	×	×	✓	×	Tensile Strength
ASTM D6878	✓	×	×	×	Weather Exposure (Only For TPO)

Standards used to support claims by roof types

Standards	Claims	TPO	PVC	Bituminous Roof	EPDM
CRRC	High Solar Reflectance	✓	✓	✕	✕
	Emissivity	✓	✓	✕	✕
Energy Star	High Energy Efficiency Performance,	✓	✓	✕	✕
	Emissivity	✓	✕	✕	✕
	High Solar Reflectance	✓	✓	✕	✕
California Title 24	High Energy Efficiency Performance,	✓	✓	✕	✕
	High Solar Reflectance	✓	✓	✕	✕
	Emissivity	✓	✓	✕	✕
LEED	High Energy Efficiency Performance,	✕	✕	✕	✕
	High Solar Reflectance	✓	✕	✕	✕
	Environmentally Friendly	✓	✓	✓	✓
ASTM D570	Durability	✕	✓	✕	✕
ISO 9001:2015	Durability	✕	✕	✓	✕
ASTM D4601	Durability	✕	✕	✓	✕
ASTM D2178	Durability	✕	✕	✓	✕
FM Standard 4470.	Durability	✕	✕	✓	✕
ASTM D 622	Durability	✕	✕	✓	✕
ASTM D 6164	Durability	✕	✕	✓	✕
ASTM G154	Durability	✕	✓	✕	✕
ASTM C1549	Solar Reflectance (Ambient Temp)	✕	✕	✕	✓
ASTM C1371	Emissivity	✕	✕	✕	✓
ASTM D4434	Durability	✕	✓	✕	✕
ASTM D4637	Durability	✕	✕	✕	✓
ASTM D6878	Durability	✓	✕	✕	✕

Conclusions – Manufacturer

- Manufacturer's claims were primarily based on certification and standards (not relying on published studies)
- Some of the manufacturer's were not supported by any certification, standards and published studies
- High Solar Reflectance: One EPDM manufacturer, six TPO manufacturers, seven PVC manufacturers, four bituminous manufacturers. Each out of a total of seventeen manufacturers.
- Energy Efficiency: Claims could only be verified for seven TPO manufacturers, six PVC manufacturers, and two bituminous manufacturers. Each out of a total of seventeen manufacturers.
- There is no dedicated certification focused on sustainable measures for EPDM roofing????
- ASTM C1549 and ASTM C1371 standards were used for solar reflectance (ambient temp) and emissivity respectively for EPDM roofing

Urban Heat Island Effect

Framework to document UHIE

01

Identifying Studies

- Research Databases

02

Reviewing the studies

- Abstract
- Methodology
- Result

03

Finding data related to UHIE

- Real World/Simulation
- Used Software
- Location
- Albedo, Solar reflectance
- Duration of the Data Capturing

04

Effect on UHIE

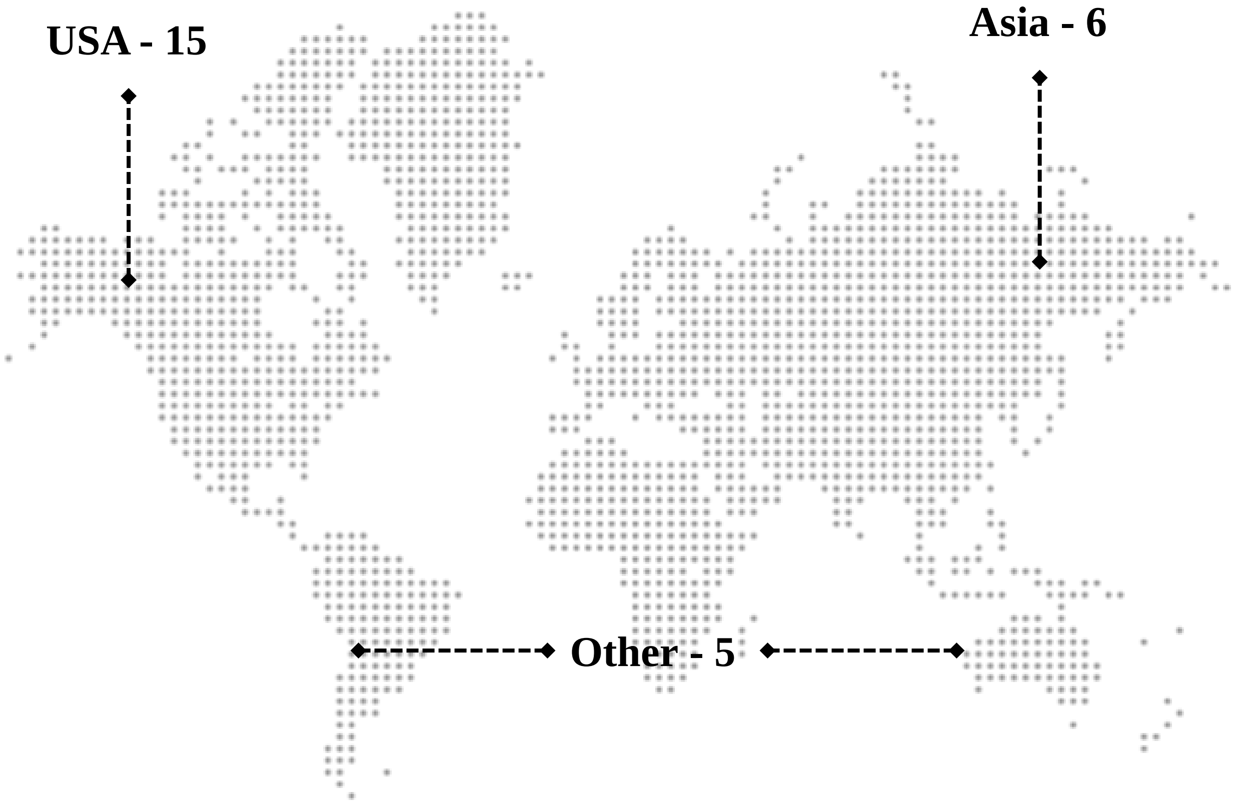
How cool roofs impact UHIE and How is the impact measured?

05

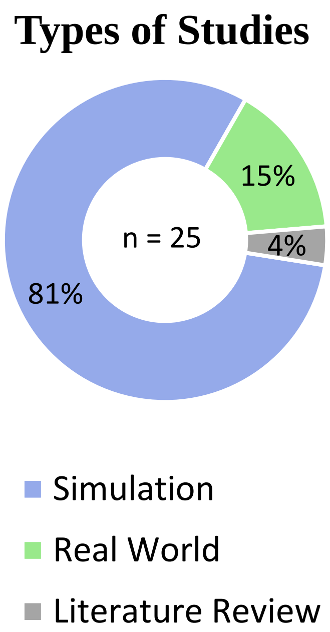
Future Path

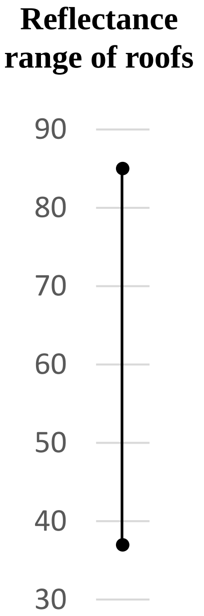
- UHIE is measured differently by different study

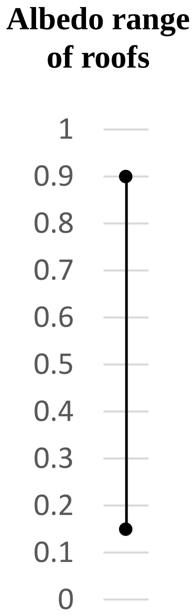
Urban Heat Island Effect – Area and Type of Studies



Total No. of Studies – 25
Simulation – 20
Real World – 4
Literature Review – 1





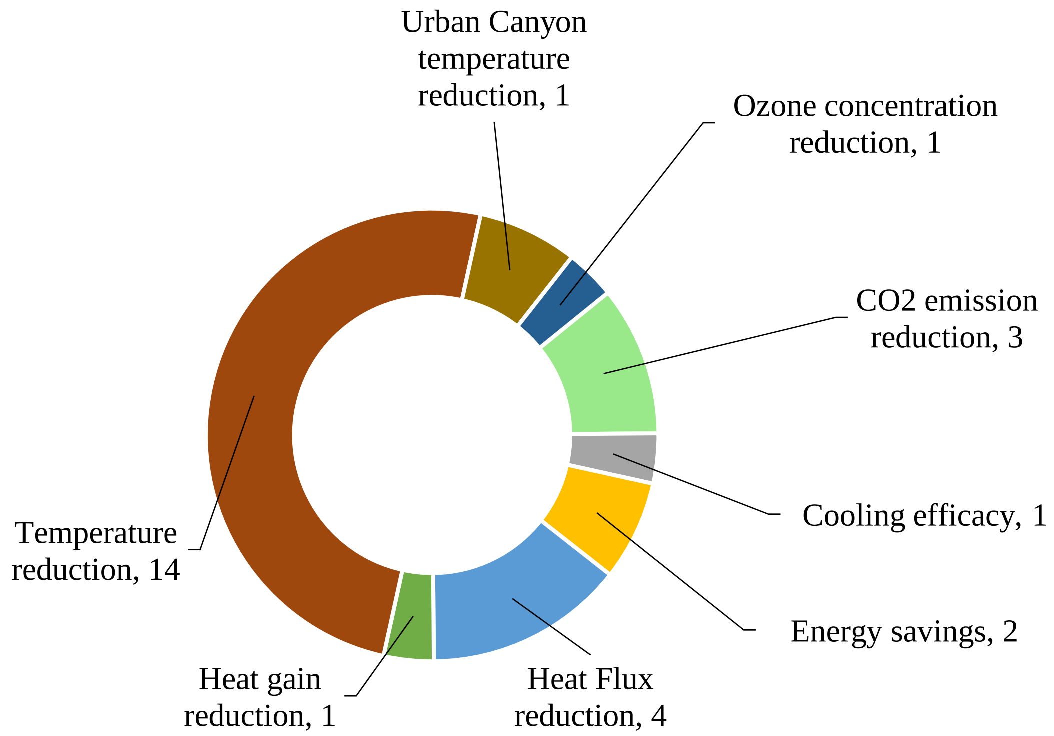


Simulation Software used

- DOE 2.1
- Energy Plus
- ENVI-met
- Trnsys
- U-HRLDAS
- WRF

Urban Heat Island Measurement Parameters

- Cool Roof impact on UHIE is studied differently by different publications



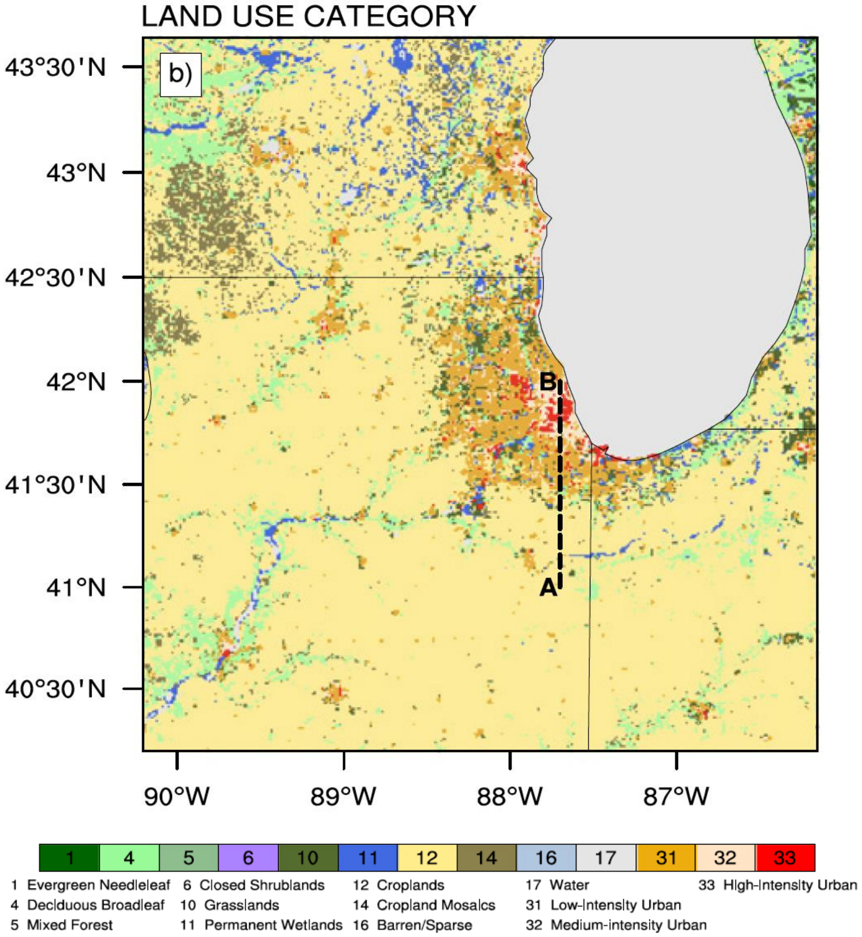
UHI Measuring Parameters

Parameters	Definition
Roof Surface Temperature (reduction)	Process of becoming cooler
Heat Flux (reduction)	The rate of heat energy that passes through a surface
Ozone concentration/pollution (reduction)	Ozone (O_3) is a gas molecule composed of three oxygen atoms. Often called "smog," ozone is harmful to breathe. Ozone aggressively attacks lung tissue by reacting chemically with it
Annual energy savings	Savings in terms of energy efficiency
CO2 emissions	Mass of greenhouse gas or air pollutant emitted per unit energy supplied to the grid
Urban Canyon temperature	An urban canyon (also known as a street canyon) is a place where the street is flanked by buildings on both sides creating a canyon-like environment.

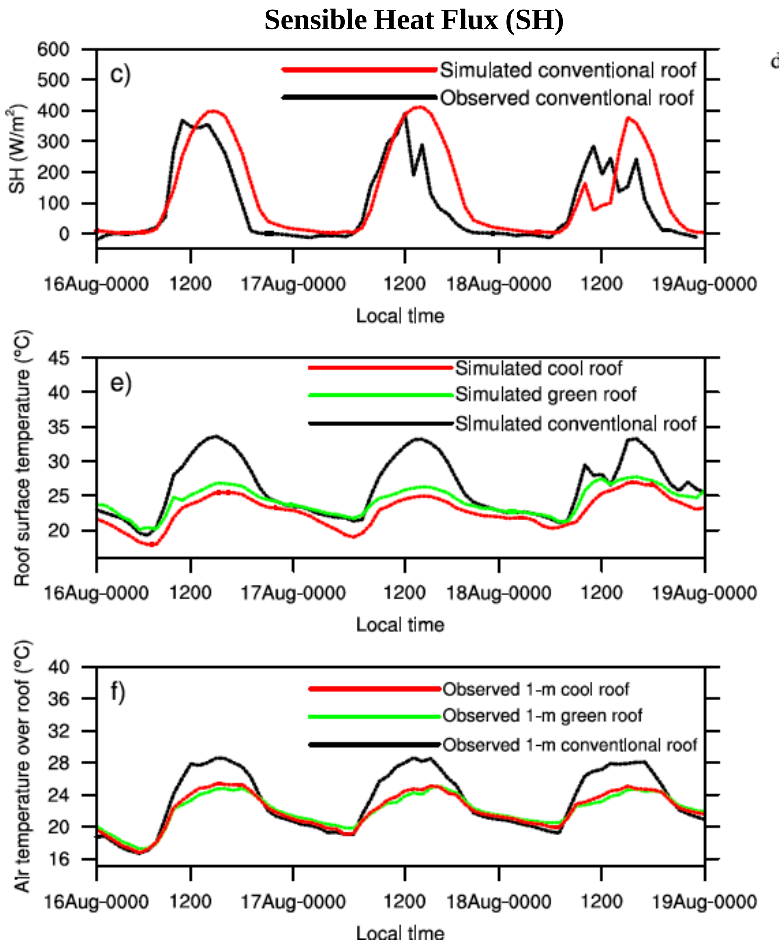
Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: Evaluation with a regional climate model (Methodology) – Sharma et. al, 2015

Roof Type	Modification
Conventional	Albedo = 0.2
Green Roof	green roof fraction 0.25, 0.5, 0.75, 1
Cool Roof	albedo = 0.85
Type of Study	Simulation - WRF
Location	Chicago
Duration	16-18 Aug 2013
UHI Effect	difference between urban and rural temperatures

Terms	Modification
Heat Flux	Flow of energy per unit of area per unit of time
Metropolitan Area	densely populated urban core
WRF model	numerical weather prediction system
Location	Chicago



❖ WRF Model Setup (Chicago Metropolitan Area)



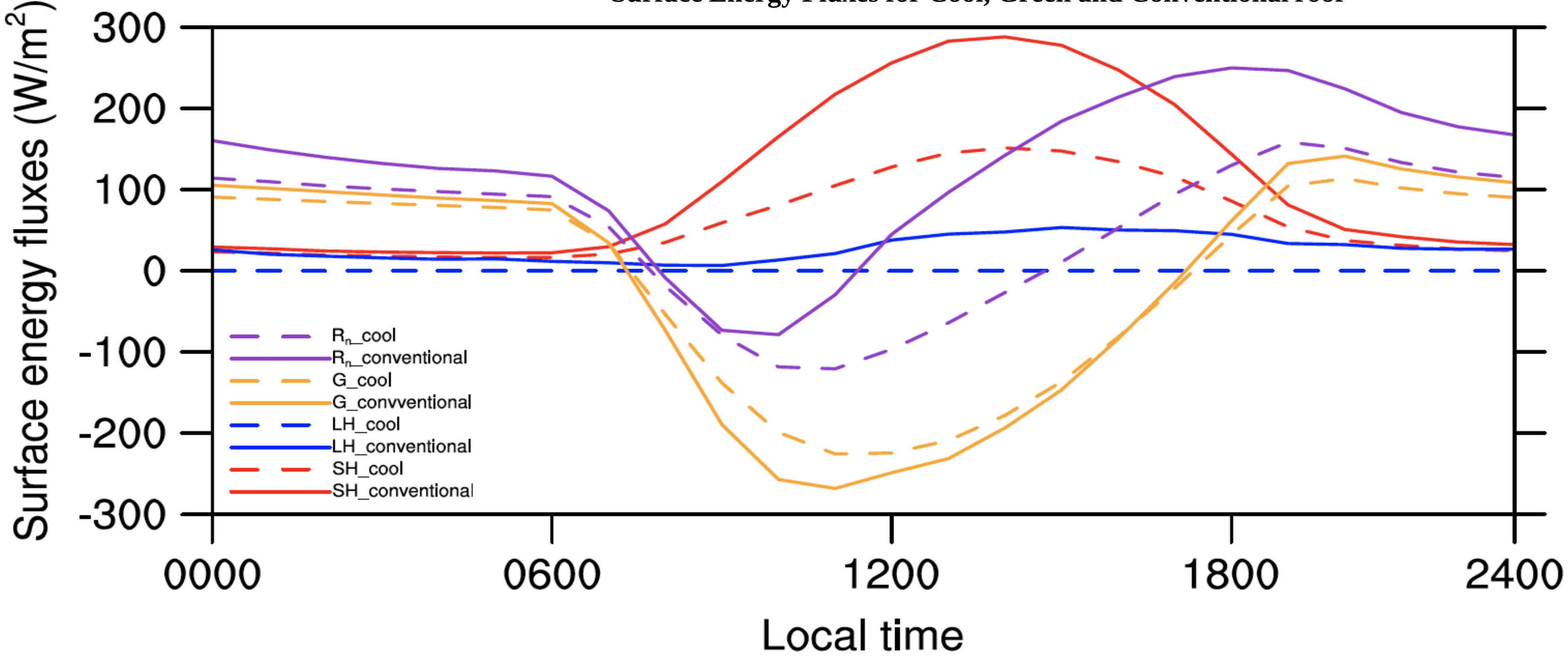
❖ Comparison of simulated and observed study

❖ Conventional Roof has the highest Surface Temperature
❖ Cool roof has the lowest surface temperature

Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: Evaluation with a regional climate model (Result) - Sharma et. al, 2015

Findings/Limitation	
Daytime Surface Temperature Reduction (Cool Roof)	7 – 8 C
Heat Flux (Cool Roof)	150 (W/M2)
Horizontal Wind Speed Decreased (near-surface 10m)	
Limitation	2 days data capturing, Summer, Simulation

Surface Energy Fluxes for Cool, Green and Conventional roof



	Modifications
Rn	The net radiation flux at the surfaces: the balance between incoming and outgoing energy at the top of the atmosphere
SH	Sensible Heat Flux: the transfer of heat caused by the difference in temperature between the sea and the air
LH	Latent Heat Flux: Flux of energy from the Earth's surface to the atmosphere
G	Storage Heat Flux: is the net uptake or release of energy (per unit area and time) by sensible heat changes in the urban canopy air layer, buildings, vegetation, and the ground

- Cool Roof Net Radiation has been lower than conventional roof throughout the data capturing period
- Cool roof Storage Heat Flux has been lower than conventional Roof throughout the data capturing period

The effectiveness of cool and green roofs as urban heat island mitigation strategies – Li et. al, 2014

Roof Type	Modification
Conventional	Albedo=0.3
Green	green roof fraction 0.1, 0.2, 0.3, 0.5, 0.7, 1
Cool	albedo=0.7
Cool	Fraction (10%, 20%, 50%, 30%, 70%, 100%)
Type of Study	Simulation - WRF
Location	Baltimore-Washington
Duration	7 - 10 June 2008

Increasing cool roof fractions can also reduce the surface and near-surface urban heat islands

e): changes in the surface urban heat island based on cool roof coverage fractions

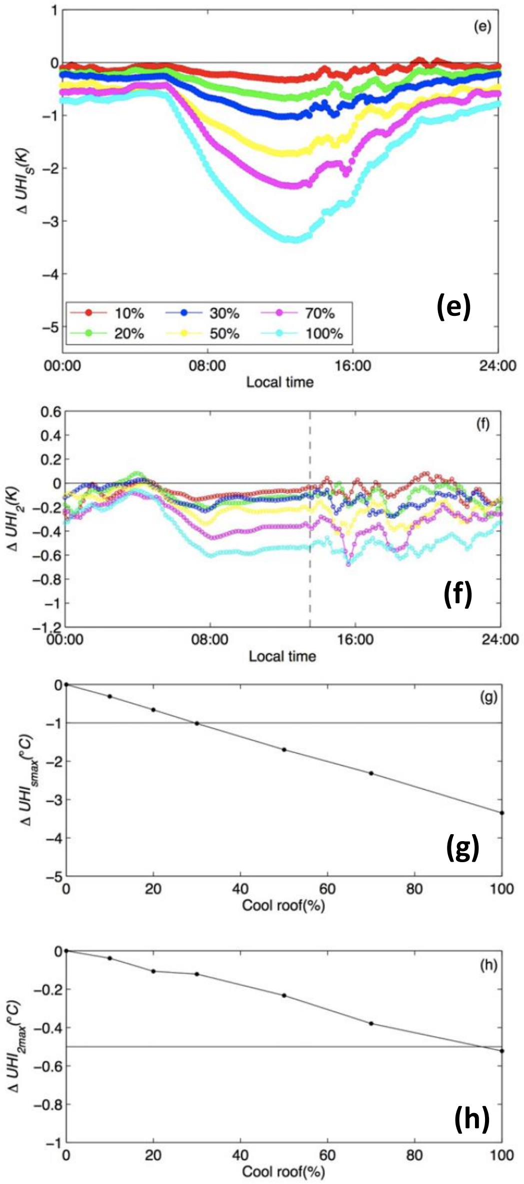
- increasing cool roof fractions can significantly reduce the daytime surface urban heat island (≈4 C), but in night (≈1 C)

f): change in near surface temperature (2m air temperature) reach their maxima

- Increasing cool roof fraction during daytime has more impact than nighttime

g, h): corresponding reductions in the surface and near-surface urban heat islands

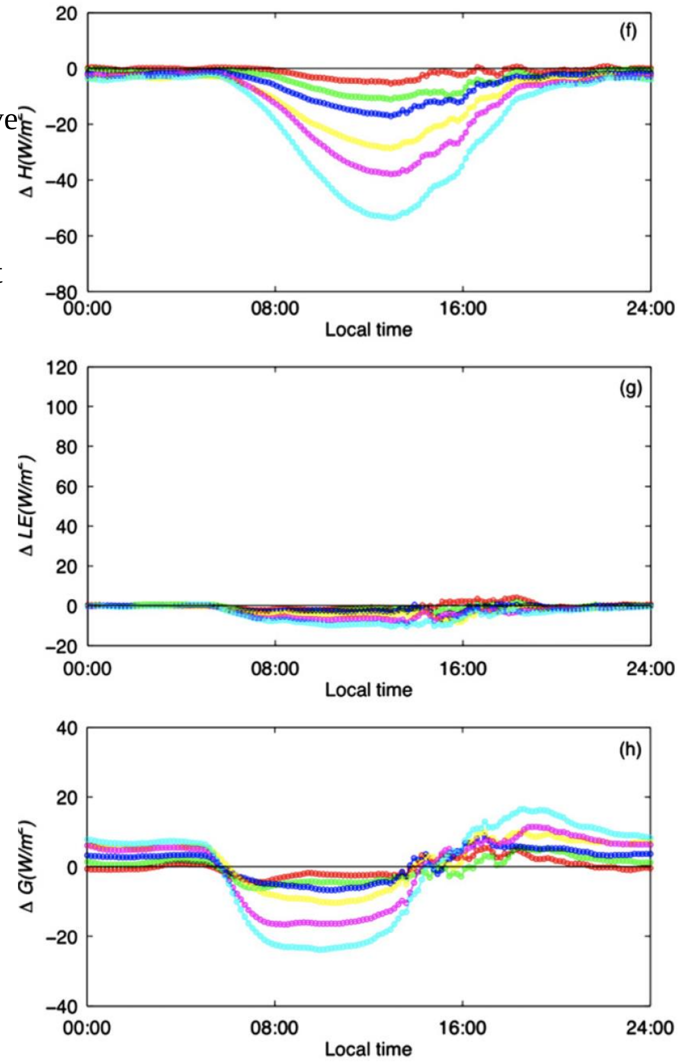
- approximately 95% cool roof coverage is needed in order to reduce the near-surface urban heat island by 0.5 °C



f): changes in the sensible heat flux
cool roof are equally effective in reducing the sensible heat flux

g): changes in the latent heat flux
the increase in cool roof fraction reduces the latent heat flux over the urban surface.

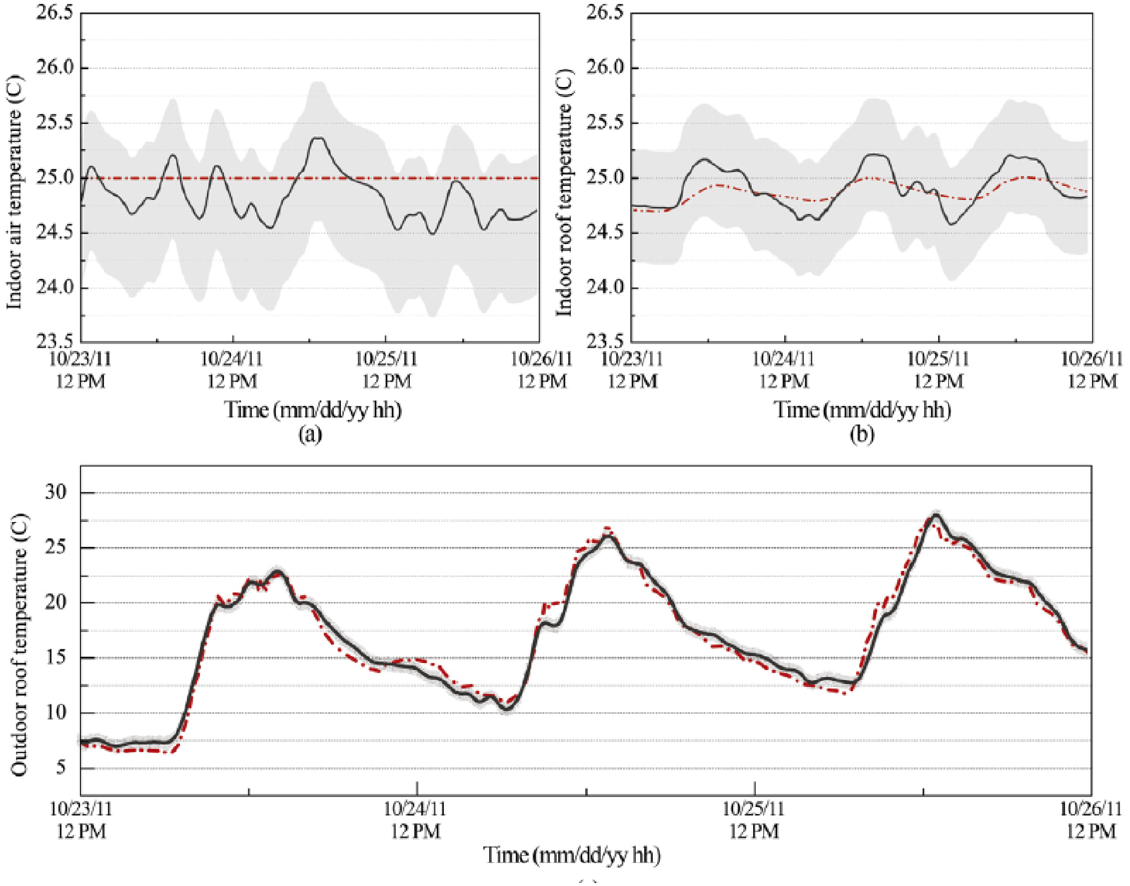
h): Change in heat storage
heat storage decreases significantly during daytime as the cool roof fractions increases



Adaptive measures for mitigating urban heat islands: The potential of thermochromic materials to control roofing energy balance – Fabiani et. al, 2019

Roof Type	Modification
Roof thickness	0.3 m
Cool Roof	Albedo = 0.55
Dark Roof	Albedo = 0.15
Thermochromic Roof Coating	albedo = 0.4
Type of Study	Experimental
Location	Laboratory

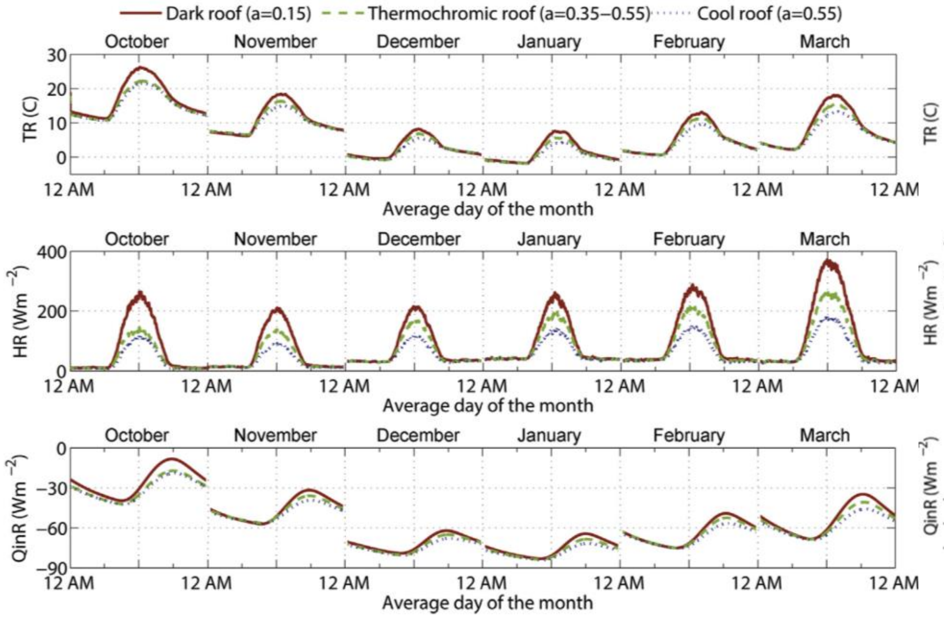
Terms	Modification
Heat Flux	Flow of energy per unit of area per unit of time
Metropolitan Area	densely populated urban core
WRF model	numerical weather prediction system
Location	Chicago

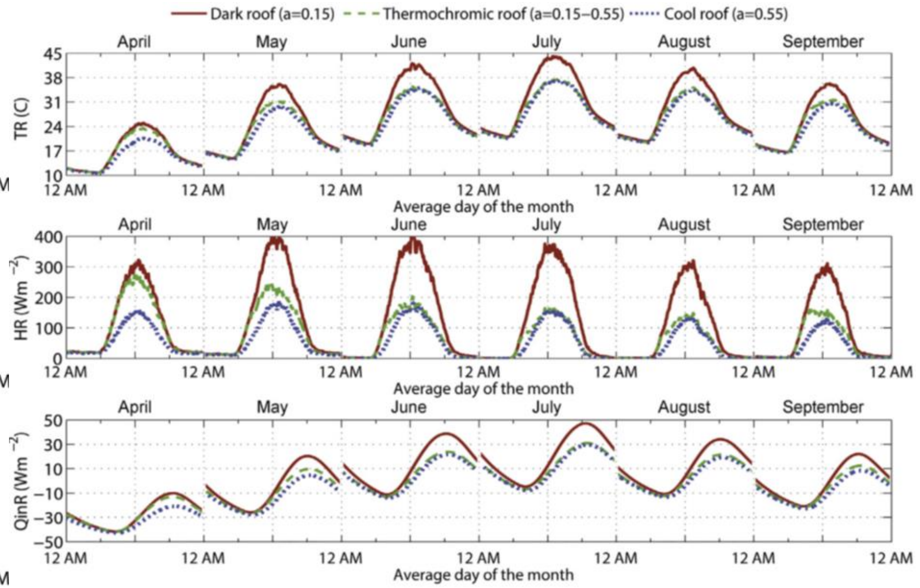


Comparison of simulated and the experimental temperature (October 23 - 26th 2011)

Adaptive measures for mitigating urban heat islands: The potential of thermochromic materials to control roofing energy balance – Fabiani et. al, 2019

Terms	Modification
Outward Heat Flux	Flow of energy per unit of area per unit of time
Inward Heat Flux	adding heat flux to the total flux across the selected boundaries
WRF model	numerical weather prediction system
Thermochromic material	thermochromic materials, i.e. parcels that respond to the surrounding environment by reversibly changing their optical properties as a function of temperature





Findings - Cold Season			
Roof	Average Roof temperature for a year	Average Outward Heat Flux for a year	Average Inward Heat Flux for a year
Thermochromic Roof Coating	12.8	180	-48
Dark Roof	14.6	261.6	-42.6
Cool Roof	11.3	101.6	-51.8

Findings - Warm Season			
Roof	Average Roof temperature for a year	Average Outward Heat Flux for a year	Average Inward Heat Flux for a year
Thermochromic Roof Coating	15.8	260	-40.6
Dark Roof	14.3	261.6	-40.5
Cool Roof	10.6	123.3	- 50.6

*Cool roof always presents the lowest surface temperature and heat fluxes (11.3 C and 101.6 W/m2)

Conclusions - Effect of Cool Roofs on Urban Heat Island (UHI)

Conclusions by Publications*

- UHI Mitigation Strategies are dependent on urban land use characteristics and meteorological conditions.
- Studies indicate that as the green and cool roof fractions increase, the surface and near-surface UHIs at the time when the surface and near-surface temperatures reach their maxima are reduced almost linearly.
- Increase in albedo is an effective way of reducing UHI.
- Cool roofs exhibit higher cooling efficacy in conditions of higher solar radiation, lower relative humidity, and less precipitation.
- Cool roofs can reduce the surface and near-surface UHIs when their performances are not hindered by dirt accumulation that reduces albedo (cool roofs).
- Keeping cool roof fraction constant and increasing albedo value could allow an additional reduction in the surface UHI.
- Citywide adoption of cool roofs could be a viable way to meaningfully offset the daytime UHI effect.
- Cool roofs change the surface energy balance by reducing solar radiation.

** Conclusions by observation and analysis require an in-depth data analysis through experimental/empirical study to validate results*

Sharma et. al, 2015; Li et. al, 2014; Fabiani et. al, 2019

References – Energy Efficiency

1. Yuan, J., Emura, K., & Farnham, C. (2016). Highly Reflective Roofing Sheets Installed on a School Building to Mitigate the Urban Heat Island Effect in Osaka. MDPI.

2. Raut, A., Khatoon, S., & Goud, P. (2019). A comparative study on effects of various insulating layers of roof system on energy usage of building envelope. IOP Conference Series: Earth and Environmental Science, 354(1). https://doi.org/10.1088/1755-1315/354/1/012055

3. Zhang, Z., Tong, S., & Yu, H. (2016). Life Cycle Analysis of Cool Roof in Tropical Areas. Procedia Engineering, 169, 392–399. https://doi.org/10.1016/j.proeng.2016.10.048

4. Radhi, H., Sharples, S., Taleb, H., & Fahmy, M. (2017). Will cool roofs improve the thermal performance of our built environment? A study assessing roof systems in Bahrain. Energy and Buildings, 135, 324–337. https://doi.org/10.1016/j.enbuild.2016.11.048

5. Ma, H., Song, J., & Guo, P. (2008). Effects of increasing roof albedo on the urban environment. 2nd International Conference on Bioinformatics and Biomedical Engineering, ICBBE 2008, 4057–4060. https://doi.org/10.1109/ICBBE.2008.515

6. Garg, V., mathur, J., Reddy, N., Gandhi, J., & Fischer, M. L. (2013). EXPERIMENTAL DETERMINATION OF COMFORT BENEFITS FROM COOL-ROOF APPLICATION TO AN UN-CONDITIONED BUILDING IN INDIA 1 Rathish Arumugam <rathish.iiit@gmail

7. He, Y., Yu, H., Ozaki, A., & Dong, N. (2020). Thermal and energy performance of green roof and cool roof: A comparison study in Shanghai area. Journal of Cleaner Production, 267. https://doi.org/10.1016/j.jclepro.2020.122205

8. Xu, T., Sathaye, J., Akbari, H., Garg, V., & Tetali, S. (2012). Quantifying the direct benefits of cool roofs in an urban setting: Reduced cooling energy use and lowered greenhouse gas emissions. Building and Environment, 48(1), 1–6. https://doi.org/10.1016/j.buildenv.2011.08.011

9. Gao, Y., Xu, J., Yang, S., Tang, X., Zhou, Q., Ge, J., Xu, T., & Levinson, R. (2014b). Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments. Energy Policy, 74(C), 190–214. https://doi.org/10.1016/j.enpol.2014.05.036

10. Yang, Y. K., Kim, M. Y., Chung, M. H., & Park, J. C. (2019). PCM cool roof systems for mitigating urban heat island - an experimental and numerical analysis. Energy and Buildings, 205. https://doi.org/10.1016/j.enbuild.2019.109537

11. ZINZI, M., & AGNOLI, S. (2012). Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region. Alma/SFX Local Collection

12. Kolokotroni, M., Gowreesunker, B. L., & Giridharan, R. (2013). Cool roof technology in London: An experimental and modelling study. Energy and Buildings, 67, 658–667. https://doi.org/10.1016/j.enbuild.2011.07.011

13. Costanzo, V., Evola, G., & Marletta, L. (2016). Energy savings in buildings or UHI mitigation? Comparison between green roofs and cool roofs. Energy and Buildings, 114, 247–255. https://doi.org/10.1016/j.enbuild.2015.04.053

14. Gagliano, A., Detommaso, M., Nocera, F., & Evola, G. (2015). A multi-criteria methodology for comparing the energy and environmental behavior of cool, green and traditional roofs. Building and Environment, 90, 71–81. https://doi.org/10.1016/j.buildenv.2015.02.043

15. Bozonnet, E., Doya, M., & Allard, F. (2011). Cool roofs impact on building thermal response: A French case study. Energy and Buildings, 43(11), 3006–3012. https://doi.org/10.1016/j.enbuild.2011.07.017

16. di Giuseppe, E., Pergolini, M., & Stazi, F. (2017). Numerical assessment of the impact of roof reflectivity and building envelope thermal transmittance on the UHI effect. Energy Procedia, 134, 404–413. https://doi.org/10.1016/j.egypro.2017.09.590

17. Pisello, A. L., Santamouris, M., & Cotana, F. (2013). Active cool roof effect: impact of cool roofs on cooling system efficiency. Advances in Building Energy Research, 7(2), 209–221. https://doi.org/10.1080/17512549.2013.865560

18. Stavrakakis, G. M., Androutsopoulos, A. v., & Vyörykkä, J. (2016). Experimental and numerical assessment of cool-roof impact on thermal and energy performance of a school building in Greece. Energy and Buildings, 130, 64–84. https://doi.org/10.1016/j.enbuild.2016.08.047

19. Romeo, C., & Zinzi, M. (2013). Impact of a cool roof application on the energy and comfort performance in an existing non-residential building. A Sicilian case study. Energy and Buildings, 67, 647–657. https://doi.org/10.1016/j.enbuild.2011.07.023

20. Pisello, A. L., Rossi, F., & Cotana, F. (2014). Summer and winter effect of innovative cool roof tiles on the dynamic thermal behavior of buildings. Energies, 7(4), 2343–2361. https://doi.org/10.3390/en7042343

21. Pisello, A. L., Cotana, F., Nicolini, A., & Brinchi, L. (2013). Development of clay tile coatings for steep-sloped cool roofs. Energies, 6(8), 3637–3653. https://doi.org/10.3390/en6083637

22. Kolokotsa, D., Diakaki, C., Papantoniou, S., & Vlissidis, A. (2012). Numerical and experimental analysis of cool roofs application on a laboratory building in Iraklion, Crete, Greece. Energy and Buildings, 55, 85–93. https://doi.org/10.1016/j.enbuild.2011.09.011

23. Cirrincione, L., Gennusa, M. la, Rizzo, G., Scaccianoce, G., & Peri, G. (2020). Comparing indoor performances of a building equipped with four different roof configurations in 65 Italian sites

24. Detommaso, M., Cascone, S., Gagliano, A., Nocera, F., & Sciuto, G. (2020). Cool roofs with variable thermal insulation: UHI mitigation and energy savings for several italian cities. Smart Innovation, Systems and Technologies, 163, 481–492. https://doi.org/10.1007/978-981-32-9868-2_41

25. Žuvela-Aloise, M., Andre, K., Schwaiger, H., Bird, D. N., & Gallaun, H. (2018). Modelling reduction of urban heat load in Vienna by modifying surface properties of roofs. Theoretical and Applied Climatology, 131(3–4), 1005–1018. https://doi.org/10.1007/s00704-016-2024-2

26. Coutts, A. M., Daly, E., Beringer, J., & Tapper, N. J. (2013). Assessing practical measures to reduce urban heat: Green and cool roofs. Building and Environment, 70, 266–276. https://doi.org/10.1016/j.buildenv.2013.08.021

27. Imran, H. M., Kala, J., Ng, A. W. M., & Muthukumaran, S. (2018). Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia. Journal of Cleaner Production, 197, 393–405. https://doi.org/10.1016/j.jclepro.2018.06.179

28. Piselli, C., Pisello, A. L., Saffari, M., de Gracia, A., Cotana, F., & Cabeza, L. F. (2019). Cool roof impact on building energy need: The role of thermal insulation with varying climate conditions. Energies, 12(17). https://doi.org/10.3390/en12173354

29. Seifhashem, M., Capra, B. R., Milller, W., & Bell, J. (2018). The potential for cool roofs to improve the energy efficiency of single storey warehouse-type retail buildings in Australia: A simulation case study. Energy and Buildings, 158, 1393–1403. https://doi.org/10.1016/j.enbuild.2017.11.034

30. Ríos-Fernández, J. C. (2021). Thermal performance assessment of cool roofs on supermarkets through case analysis in 13 cities. Engineering, Construction and Architectural Management. https://doi.org/10.1108/ECAM-11-2020-0919

31. Chen, J., Lu, L., Gong, Q., Lau, W. Y., & Cheung, K. H. (2021). Techno-economic and environmental performance assessment of radiative sky cooling-based super-cool roof applications in China. Energy Conversion and Management, 245. https://doi.org/10.1016/j.enconman.2021.114621

32. Synnefa, A., Santamouris, M., & Akbari, H. (2007). Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. Energy and Buildings, 39(11), 1167–1174. https://doi.org/10.1016/j.enbuild.2007.01.004

33. Copyright, & Ashrae. (2007). Cool Roofs and Thermal Insulation: Energy Savings and Peak Demand Reduction

References – Energy Efficiency

34. Saber, H. H., Swinton, M. C., Kalinger, P., & Paroli, R. M. (2012). Long-term hygrothermal performance of white and black roofs in North American climates. Building and Environment, 50, 141–154. https://doi.org/10.1016/j.buildenv.2011.10.022

35. Konopacki, S., & Akbari, H. (2001). Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin

36. Hosseini, M., Lee, B., & Vakilinia, S. (2017a). Energy performance of cool roofs under the impact of actual weather data. Energy and Buildings, 145, 284–292. https://doi.org/10.1016/j.enbuild.2017.04.006

37. Kolokotroni, M., Shittu, E., Santos, T., Ramowski, L., Mollard, A., Rowe, K., Wilson, E., Filho, J. P. de B., & Novieto, D. (2018). Cool roofs: High tech low cost solution for energy efficiency and thermal comfort in low rise low income houses in high solar radiation countries. Energy and Buildings, 176, 58–70. https://doi.org/10.1016/j.enbuild.2018.07.005"

38. Shittu, E., Stojceska, V., Gratton, P., & Kolokotroni, M. (2020). Environmental impact of cool roof paint: case-study of house retrofit in two hot islands. Energy & Buildings, 217, 7. https://doi.org/10.1016/j.enbuild.2020.110

39. Brito Filho, J. P., & Santos, T. V. O. (2014). Thermal analysis of roofs with thermal insulation layer and reflective coatings in subtropical and equatorial climate regions in Brazil. Energy and Buildings, 84, 466–474. https://doi.org/10.1016/j.enbuild.2014.08.042

40. Gaffin, S. R., Imhoff, M., Rosenzweig, C., Khanbilvardi, R., Pasqualini, A., Kong, A. Y. Y., Grillo, D., Freed, A., Hillel, D., & Hartung, E. (2012). Bright is the new blackmulti-year performance of high-albedo roofs in an urban climate. Environmental Research Letters, 7(1). https://doi.org/10.1088/1748-9326/7/1/014029

41. Cubi, E., Zibin, N. F., Thompson, S. J., & Bergerson, J. (2016). Sustainability of Rooftop Technologies in Cold Climates: Comparative Life Cycle Assessment of White Roofs, Green Roofs, and Photovoltaic Panels. Journal of Industrial Ecology, 20(2), 249–262. https://doi.org/10.1111/jiec.12269

42. Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., & Martilli, A. (2016). Citywide Impacts of Cool Roof and Rooftop Solar Photovoltaic Deployment on Near-Surface Air Temperature and Cooling Energy Demand. Boundary-Layer Meteorology, 161(1), 203–221. https://doi.org/10.1007/s10546-016-0160-y

43. Ramamurthy, P., Sun, T., Rule, K., & Bou-Zeid, E. (2015). The joint influence of albedo and insulation on roof performance: An observational study. Energy and Buildings, 93, 249–258. https://doi.org/10.1016/j.enbuild.2015.02.040

44. Ferrando, M., Hong, T., & Causone, F. (2021). A simulation-based assessment of technologies to reduce heat emissions from buildings. Building and Environment, 195. https://doi.org/10.1016/j.buildenv.2021.107772

45. Ganguly, A., Chowdhury, D., & Neogi, S. (2016). Performance of Building Roofs on Energy Efficiency - A Review. Energy Procedia, 90, 200–208. https://doi.org/10.1016/j.egypro.2016.11.186

46. Arumugam, R. S., Garg, V., Ram, V. V., & Bhatia, A. (2015). Optimizing roof insulation for roofs with high albedo coating and radiant barriers in India. Journal of Building Engineering, 2, 52–58. https://doi.org/10.1016/j.jobe.2015.04.004

47. Ashtari, B., Yeganeh, M., Bemanian, M., & Vojdani Fakhr, B. (2021). A Conceptual Review of the Potential of Cool Roofs as an Effective Passive Solar Technique: Elaboration of Benefits and Drawbacks. In Frontiers in Energy Research (Vol. 9). Frontiers Media S.A. https://doi.org/10.3389/fenrg.2021.738182

48. Jo, J. H., Carlson, J. D., Golden, J. S., & Bryan, H. (2010). An integrated empirical and modeling methodology for analyzing solar reflective roof technologies on commercial buildings. Building and Environment, 45(2), 453–460. https://doi.org/10.1016/j.buildenv.2009.07.001

49. Virk, G., Jansz, A., Mavrogianni, A., Mylona, A., Stocker, J., & Davies, M. (2015). Microclimatic effects of green and cool roofs in London and their impacts on energy use for a typical office building. Energy and Buildings, 88, 214–228. https://doi.org/10.1016/j.enbuild.2014.11.039

50. Zhang, J., Zhang, K., Liu, J., & Ban-Weiss, G. (2016). Revisiting the climate impacts of cool roofs around the globe using an Earth system model. Environmental Research Letters, 11(8). https://doi.org/10.1088/1748-9326/11/8/084014

51. Roman, K. K., O'Brien, T., Alvey, J. B., & Woo, O. J. (2016). Simulating the effects of cool roof and PCM (phase change materials) based roof to mitigate UHI (urban heat island) in prominent US cities. Energy, 96, 103–117. https://doi.org/10.1016/j.energy.2015.11.082

52. Hosseini, M., Lee, B., & Vakilinia, S. (2017b). Energy performance of cool roofs under the impact of actual weather data. Energy and Buildings, 145, 284–292. https://doi.org/10.1016/j.enbuild.2017.04.006

53. VanCuren, R. (2012). The radiative forcing benefits of "cool roof" construction in California: Quantifying the climate impacts of building albedo modification. Climatic Change, 112(3–4), 1071–1083. https://doi.org/10.1007/s10584-011-0250-2

54. Antonaia, A., Ascione, F., Castaldo, A., D'Angelo, A., de Masi, R. F., Ferrara, M., Vanoli, G. P., & Vitiello, G. (2016). Cool materials for reducing summer energy consumptions in Mediterranean climate: In-lab experiments and numerical analysis of a new coating based on acrylic paint. Applied Thermal Engineering, 102, 91–107. https://doi.org/10.1016/j.applthermaleng.2016.03.111

55. Levinson, R., Akbari, H., Konopacki, S., & Bretz, S. (2002). Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements

56. Li, X. X., & Norford, L. K. (2016b). Evaluation of cool roof and vegetations in mitigating urban heat island in a tropical city, Singapore. Urban Climate, 16, 59–74. https://doi.org/10.1016/j.uclim.2015.12.002

57. Martin-Dominguez, I. R., Lucero Álvarez, J., & Alarcón-Herrera, M. T. (2015). The Effect of Solar Reflectance, Infrared Emissivity, and Thermal Insulation of Roofs on the Annual Thermal Load of Single-family Households in México. 1–9. https://doi.org/10.18086/eurosun.2014.13.03

58. Gao, Y., Xu, J., Yang, S., Tang, X., Zhou, Q., Ge, J., Xu, T., & Levinson, R. (2014a). Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments. Energy Policy, 74(C), 190–214. https://doi.org/10.1016/j.enpol.2014.05.036

59. Rosenfeld, A. H., Akbari, H., Bretz, S., Fishman, B. L., Kurn, D. M., Sailor, D., & Taha, H. (1995). Mitigation of urban heat islands: materials, utility programs,. In Energy and Buildings (Vol. 22)

60. Akbari, H., Konopacki, S., & Pomerantz, M. (1999). Cooling energy savings potential of reflective roofs for residential and commercial buildings in the United States. In Energy (Vol. 24)

61. Akbari, H., Bretz, S., Km-N, D. M., & Hanford, J. (1997). Peak power and cooling energy savings of high-albedo roofs

62. Akbari, H., Bretz, S., Hartford, J., Rosenfeld, A., Sailor, D., Taha, H., & Bos, W. (1992). Monitoring Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces in the Sacramento Municipal Utility District (SMI_) Service Area: Project Design and Preliminary Results

63. Bal'ut, H. A., & Taha, H. (1991). THE IMPACT OF TREES AND WHITE SURFACES ON RESIDENTIAL HEATING AND COOLING ENERGY USE IN FOUR CANADIAN CITIES. In EMrgy (Vol. 17, Issue 2)

64. Parker Subrato Chandra Stephen F Barkaszi Jr David J Beal, D. S. (n.d.). MEASURED COOLING ENERGY SAVINGS FROM REFLECTIVE ROOFING SYSTEMS IN FLORIDA: FIELD AND LABORATORY RESEARCH RESULTS

65. Parker, D. S. ;, Huang, Y. J. ;, Konopacki, S. J. ;, & Gartland, L. M. (1998). Measured and Simulated Performance of Reflective Roofing Systems in Residential Building. In ASHRAE Transactions (Vol. 104)

References – Energy Efficiency / Urban Heat Island

66. Akbari, H., Gartland, L., & Konopacki, S. (1998). Measured energy savings of light-colored roofs: results from three California demonstration sites

67. Grant, E. J., Black, K. A., & Werre, S. R. (2017). The influence of roof reflectivity on adjacent air and surface temperatures. Architectural Science Review, 60(2), 137–144. https://doi.org/10.1080/00038628.2017.1300870

68. Tzempelikos, A., & Lee, S. (2021). Cool roofs in the us: The impact of roof reflectivity, insulation and attachment method on annual energy cost. Energies, 14(22). https://doi.org/10.3390/en14227656

69. Taylor, T. J. (2019). Reflective roofing use on commercial buildings in the United States: An energy type and cost analysis. Buildings, 9(10). https://doi.org/10.3390/buildings9100212

70. Molleti, S., Carrigan, L., & van Reenen, D. (2021). Mean operating temperature (Mot) of commercial roof assembly and its impact on the energy performance. Buildings, 11(5). https://doi.org/10.3390/buildings11050216

71. Sproul, J., Wan, M. P., Mandel, B. H., & Rosenfeld, A. H. (2014). Economic comparison of white, green, and black flat roofs in the United States. Energy and Buildings, 71, 20–27. https://doi.org/10.1016/j.enbuild.2013.11.058

72. Levinson, & Akbari, H. (2009). Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy Efficiency, 3(1), 53–109. https://doi.org/10.1007/s12053-008-9038-2

73. Hosseini, Mirata, and Hashem Akbari. “Effect of Cool Roofs on Commercial Buildings Energy Use in Cold Climates.” Energy and buildings 114 (2016): 143–155. Web.

74. Barozzi, Benedetta, and M. Pollastro. “Assessment of the Impact of Cool Roofs in Temperate Climates through a Comparative Experimental Campaign in Outdoor Test Cells.” Buildings (Basel) 6.4 (2016): 52–. Web.

75. Rosado, Pablo J et al. “Measured Temperature Reductions and Energy Savings from a Cool Tile Roof on a Central California Home.” Energy and buildings 80 (2014): 57–71. Web.

76. Akbari, H. “Measured Energy Savings from the Application of Reflective Roofs in Two Small Non-Residential Buildings.” Energy (Oxford) 28.9 (2003): 953–967. Web.

77. Taha, Haider et al. “Residential Cooling Loads and the Urban Heat Island—the Effects of Albedo.” Building and environment 23.4 (1988): 271–283. Web.

78. Gao, M., Chen, F., Shen, H., & Li, H. (2020). A tale of two cities: different urban heat mitigation efficacy with the same strategies. https://doi.org/10.1007/s00704-020-03390-2/Published

79. 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(3). https://doi.org/10.1029/2009GL042194

80. Sharma, A., Conry, P., Fernando, H. J. S., Hamlet, A. F., Hellmann, J. J., & Chen, F. (2016). Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: Evaluation with a regional climate model. Environmental Research Letters, 11(6). https://doi.org/10.1088/1748-9326/11/6/064004

81. Kolokotsa, D., Santamouris, M., & Zerefos, S. C. (2013). Green and cool roofs’ urban heat island mitigation potential in European climates for office buildings under free floating conditions. Solar Energy, 95, 118–130. https://doi.org/10.1016/j.solener.2013.06.001

82. Zhang, J., Li, Y., Tao, W., Liu, J., Levinson, R., Mohegh, A., & Ban-Weiss, G. (2019). Investigating the urban air quality effects of cool walls and cool roofs in Southern California. Environmental Science and Technology, 53(13), 7532–7542. https://doi.org/10.1021/acs.est.9b00626

83. Shickman, K., & Rogers, M. (2020). Capturing the true value of trees, cool roofs, and other urban heat island mitigation strategies for utilities. Energy Efficiency, 13(3), 407–418. https://doi.org/10.1007/s12053-019-09789-9

84. Li, D., Bou-Zeid, E., & Oppenheimer, M. (2014a). The effectiveness of cool and green roofs as urban heat island mitigation strategies. Environmental Research Letters, 9(5). https://doi.org/10.1088/1748-9326/9/5/055002

85. Vahmani, P., Sun, F., Hall, A., & Ban-Weiss, G. (2016). Investigating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California. Environmental Research Letters, 11(12). https://doi.org/10.1088/1748-9326/11/12/124027

86. Chen, Y., & Zhang, N. (2018). Urban heat island mitigation effectiveness under extreme heat conditions in the Suzhou-Wuxi-Changzhou Metropolitan area, China. Journal of Applied Meteorology and Climatology, 57(2), 235–253. https://doi.org/10.1175/JAMC-D-17-0101.1

87. Pisello, A. L., Castaldo, V. L., Pignatta, G., Cotana, F., & Santamouris, M. (2016). Experimental in-lab and in-field analysis of waterproof membranes for cool roof application and urban heat island mitigation. Energy and Buildings, 114, 180–190. https://doi.org/10.1016/j.enbuild.2015.05.026

88. Abuseif, M., & Gou, Z. (2018). A review of roofing methods: Construction features, heat reduction, payback period and climatic responsiveness. In Energies (Vol. 11, Issue 11). MDPI AG. https://doi.org/10.3390/en11113196

89. Middel, A., Chhetri, N., & Quay, R. (2015). Urban forestry and cool roofs: Assessment of heat mitigation strategies in Phoenix residential neighborhoods. Urban Forestry and Urban Greening, 14(1), 178–186. https://doi.org/10.1016/j.ufug.2014.09.010

90. Zhang, J., Mohegh, A., Li, Y., Levinson, R., & Ban-Weiss, G. (2018). Systematic Comparison of the Influence of Cool Wall versus Cool Roof Adoption on Urban Climate in the Los Angeles Basin. Environmental Science and Technology, 52(19), 11188–11197. https://doi.org/10.1021/acs.est.8b00732

91. Zinzi, M., & Fasano, G. (2009). Properties and performance of advanced reflective paints to reduce the cooling loads in buildings and mitigate the heat island effect in urban areas. International Journal of Sustainable Energy, 28(1–3), 123–139. https://doi.org/10.1080/14786450802453314

92. Fabiani, C., Pisello, A. L., Bou-Zeid, E., Yang, J., & Cotana, F. (2019). Adaptive measures for mitigating urban heat islands: The potential of thermochromic materials to control roofing energy balance. Applied Energy, 247, 155–170. https://doi.org/10.1016/j.apenergy.2019.04.020

93. Cao, M., Rosado, P., Lin, Z., Levinson, R., & Millstein, D. (2015). Cool Roofs in Guangzhou, China: Outdoor Air Temperature Reductions during Heat Waves and Typical Summer Conditions. Environmental Science and Technology, 49(24), 14672–14679. https://doi.org/10.1021/acs.est.5b04886

94. Wray, C., & Akbari, H. (2008). The effects of roof reflectance on air temperatures surrounding a rooftop condensing unit. Energy and Buildings, 40(1), 11–28. https://doi.org/10.1016/j.enbuild.2007.01.005

References – Urban Heat Island

95. Akbari, H., & Konopacki, S. (2005). Calculating energy-saving potentials of heat-island reduction strategies. Energy Policy, 33(6), 721–756. https://doi.org/10.1016/j.enpol.2003.10.001

96. Jacobson, M. Z., & ten Hoeve, J. E. (2012). Effects of urban surfaces and white roofs on global and regional climate. Journal of Climate, 25(3), 1028–1044. https://doi.org/10.1175/JCLI-D-11-00032.1

97. Yang, Y. K., Kang, I. S., Chung, M. H., Kim, S. M., & Park, J. C. (2017). Effect of PCM cool roof system on the reduction in urban heat island phenomenon. Building and Environment, 122, 411–421. https://doi.org/10.1016/j.buildenv.2017.06.015

98. Akbari, H., Menon, S., & Rosenfeld, A. (2009). Global cooling: Increasing world-wide urban albedos to offset CO 2. Climatic Change, 94(3–4), 275–286. https://doi.org/10.1007/s10584-008-9515-9

99. Akbari, H., & Rose, L. S. (2008). 23.Urban Surfaces and Heat Island Mitigation Potentials. https://doi.org/10.1618/jhes.11.85

100. Akbari, H., Menon, S., & Rosenfeld, A. (2007). Global Cooling: Effect of Urban Albedo on Global Temperature

101. Konopacki, S., & Akbari, H. (2002). Energy Savings of Heat-Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Salt Lake City)

102. Li, X. X., & Norford, L. K. (2016a). Evaluation of cool roof and vegetations in mitigating urban heat island in a tropical city, Singapore. Urban Climate, 16, 59–74. https://doi.org/10.1016/j.uclim.2015.12.002

contd.

References – Built Environment

1. Ingrao, Messineo, A., Beltramo, R., Yigitcanlar, T., & Ioppolo, G. (2018). How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance. Journal of Cleaner Production, 201, 556–569. https://doi.org/10.1016/j.jclepro.2018.08.080

2. Bouw, Noorman, K. J., Wiekens, C. J., & Faaij, A. (2021). Local energy planning in the built environment: An analysis of model characteristics. Renewable & Sustainable Energy Reviews, 144, 111030–. https://doi.org/10.1016/j.rser.2021.111030

3. Halhoul Merabet, Essaaidi, M., Ben Haddou, M., Qolomany, B., Qadir, J., Anan, M., Al-Fuqaha, A., Abid, M. R., & Benhaddou, D. (2021). Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques. Renewable & Sustainable Energy Reviews, 144, 110969–. https://doi.org/10.1016/j.rser.2021.110969

4. Gassar, & Cha, S. H. (2020). Energy prediction techniques for large-scale buildings towards a sustainable built environment: A review. Energy and Buildings, 224, 110238–. https://doi.org/10.1016/j.enbuild.2020.110238

5. Antoszewski, Świerk, D., & Krzyżaniak, M. (2020). Statistical Review of Quality Parameters of Blue-Green Infrastructure Elements Important in Mitigating the Effect of the Urban Heat Island in the Temperate Climate (C) Zone. International Journal of Environmental Research and Public Health, 17(19), 1–. https://doi.org/10.3390/ijerph17197093

6. Abdelrahman, Zhan, S., Miller, C., & Chong, A. (2021). Data science for building energy efficiency: A comprehensive text-mining driven review of scientific literature. Energy and Buildings, 242. https://doi.org/10.1016/j.enbuild.2021.110885

7. Milan Sijakovic, & Ana Peric. (2021). Sustainable architectural design: towards climate change mitigation. ArchNet-IJAR, 15(2), 385–400. https://doi.org/10.1108/ARCH-05-2020-0097

8. Susca, & Pomponi, F. (2020). Heat island effects in urban life cycle assessment: Novel insights to include the effects of the urban heat island and UHI-mitigation measures in LCA for effective policy making. Journal of Industrial Ecology, 24(2), 410–423. https://doi.org/10.1111/jiec.12980

9. Cao, Fang, X., Wang, J., Li, G., Cao, Y., & Li, Y. (2020). Measuring the Urban Particulate Matter Island Effect with Rapid Urban Expansion. International Journal of Environmental Research and Public Health, 17(15), 5535–. https://doi.org/10.3390/ijerph17155535

10. Göswein, Rodrigues, C., Silvestre, J. D., Freire, F., Habert, G., & König, J. (2020). Using anticipatory life cycle assessment to enable future sustainable construction. Journal of Industrial Ecology, 24(1), 178–192. https://doi.org/10.1111/jiec.12916

11. Islam, Jollands, M., & Setunge, S. (2015). Life cycle assessment and life cycle cost implication of residential buildings—A review. Renewable & Sustainable Energy Reviews, 42, 129–140. https://doi.org/10.1016/j.rser.2014.10.006

12. Abd Rashid, & Yusoff, S. (2015). A review of life cycle assessment method for building industry. Renewable & Sustainable Energy Reviews, 45, 244–248. https://doi.org/10.1016/j.rser.2015.01.043

13. Mirabella, & Allacker, K. (2021). The population equivalent as a novel approach for life cycle assessment of cities and inter-city comparisons. The International Journal of Life Cycle Assessment, 26(8), 1623–1647. https://doi.org/10.1007/s11367-021-01944-8

14. Lotteau, Loubet, P., Pousse, M., Dufrasnes, E., & Sonnemann, G. (2015). Critical review of life cycle assessment (LCA) for the built environment at the neighborhood scale. Building and Environment, 93, 165–178. https://doi.org/10.1016/j.buildenv.2015.06.029

15. Anderson, Wulfhorst, G., & Lang, W. (2015). Energy analysis of the built environment—A review and outlook. Renewable & Sustainable Energy Reviews, 44, 149–158. https://doi.org/10.1016/j.rser.2014.12.027

16. Pomponi, & Moncaster, A. (2016). Embodied carbon mitigation and reduction in the built environment – What does the evidence say? Journal of Environmental Management, 181, 687–700. https://doi.org/10.1016/j.jenvman.2016.08.036

17. O'Malley, Piroozfar, P., Farr, E. R. ., & Pomponi, F. (2015). Urban Heat Island (UHI) mitigating strategies: A case-based comparative analysis. Sustainable Cities and Society, 19, 222–235. https://doi.org/10.1016/j.scs.2015.05.009

18. Schaubroeck, Schaubroeck, S., Heijungs, R., Zamagni, A., Brandão, M., & Benetto, E. (2021). Attributional & consequential life cycle assessment: Definitions, conceptual characteristics and modelling restrictions. Sustainability (Basel, Switzerland), 13(13), 1–47.

19. Eberhardt, van Stijn, A., Rasmussen, F. N., Birkved, M., & Birgisdottir, H. (2020). Development of a life cycle assessment allocation approach for circular economy in the built environment. Sustainability (Basel, Switzerland), 12(22), 9579–. https://doi.org/10.3390/su12229579

20. Tokede, Love, P. E. ., & Ahiaga-Dagbui, D. D. (2018). Life cycle option appraisal in retrofit buildings. Energy and Buildings, 178, 279–293. https://doi.org/10.1016/j.enbuild.2018.08.034

21. Trigaux, Wijnants, L., De Troyer, F., & Allacker, K. (2016). Life cycle assessment and life cycle costing of road infrastructure in residential neighbourhoods. The International Journal of Life Cycle Assessment, 22(6), 938–951. https://doi.org/10.1007/s11367-016-1190-x

22. Sharma, & Gupta, K. (2019). Life cycle modeling for environmental management: a review of trends and linkages. Environmental Monitoring and Assessment, 192(1), 51–51. https://doi.org/10.1007/s10661-019-8026-7

23. Ioppolo, Traverso, M., & Finkbeiner, M. (2019). Preface—a new paradigm for life cycle thinking: exploring sustainability in urban development scenarios. The International Journal of Life Cycle Assessment, 24(7), 1169–1173. https://doi.org/10.1007/s11367-019-01586-x

24. Clarke, Johnstone, C. M., Kelly, N. J., Strachan, P. A., & Tuohy, P. (2008). The role of built environment energy efficiency in a sustainable UK energy economy. Energy Policy, 36(12), 4605–4609. https://doi.org/10.1016/j.enpol.2008.09.004

25. Yearwood Travezan, Harmsen, R., & van Toledo, G. (2013). Policy analysis for energy efficiency in the built environment in Spain. Energy Policy, 61(October 2013), 317–326. https://doi.org/10.1016/j.enpol.2013.05.096

26. Strielkowski, Sherstobitova, A., Rovny, P., & Evteeva, T. (2021). Increasing Energy Efficiency and Modernization of Energy Systems in Russia: A Review. Energies (Basel), 14(11), 3164–. https://doi.org/10.3390/en14113164

27. Bauer. (2020). Interaction of Urban Heat Island Effects and Land–Sea Breezes during a New York City Heat Event. Journal of Applied Meteorology and Climatology, 59(3), 477–495. https://doi.org/10.1175/JAMC-D-19-0061.1

28. Leal Filho, Echevarria Icaza, L., Omeche Emanche, V., & Quasem Al-Amin, A. (2017). An Evidence-Based Review of Impacts, Strategies and Tools to Mitigate Urban Heat Islands. International Journal of Environmental Research and Public Health, 14(12), 1600–. https://doi.org/10.3390/ijerph14121600

29. De Meester, Dewulf, J., Verbeke, S., Janssens, A., & Van Langenhove, H. (2009). Exergetic life-cycle assessment (ELCA) for resource consumption evaluation in the built environment. Building and Environment, 44(1), 11–17. https://doi.org/10.1016/j.buildenv.2008.01.004

30. Anderson, Wulfhorst, G., & Lang, W. (2015). Expanding the use of life-cycle assessment to capture induced impacts in the built environment. Building and Environment, 94, 403–416. https://doi.org/10.1016/j.buildenv.2015.08.008

31. Ji, Lee, B., & Yi, M. Y. (2021). Building life-span prediction for life cycle assessment and life cycle cost using machine learning: A big data approach. Building and Environment, 205, 108267–. https://doi.org/10.1016/j.buildenv.2021.108267

32. Collin, Olesen, G. G. H., & Qvist Secher, A. (2019). A case-based study on the use of life cycle assessment and life cycle costing in the building industry. IOP Conference Series. Earth and Environmental Science, 323(1), 12163–. https://doi.org/10.1088/1755-1315/323/1/012163

33. Kania, Kwiecień, K., Malinowski, M., & Gliniak, M. (2021). Analyses of the Life Cycles and Social Costs of CO2 Emissions of Single-Family Residential Buildings: A Case Study in Poland. Sustainability (Basel, Switzerland), 13(11), 6164–. https://doi.org/10.3390/su13116164

34. Šekularac, Ivanović-Šekularac, J., Petrovski, A., Macut, N., & Radojević, M. (2020). Restoration of a Historic Building in Order to Improve Energy Efficiency and Energy Saving—Case Study—The Dining Room within the Žiča Monastery Property. Sustainability (Basel, Switzerland), 12(15), 6271–. https://doi.org/10.3390/su12156271

References – Built Environment

35. Đukić, & Zidar, M. (2021). Sustainability of Investment Projects with Energy Efficiency and Non-Energy Efficiency Costs: Case Examples of Public Buildings. Sustainability (Basel, Switzerland), 13(11), 5837–. https://doi.org/10.3390/su13115837

36. Thaleia Konstantinou, Tim de Jonge, Leo Oorschot, Sabira El Messlaki, Clarine van Oel, & Thijs Asselbergs. (2020). The relation of energy efficiency upgrades and cost of living, investigated in two cases of multi-residential buildings in the Netherlands. Smart and Sustainable Built Environment, 9(4), 615–633. https://doi.org/10.1108/SASBE-04-2019-0044

37. Lu, Li, C., Yu, C., Jin, M., & Dong, S. (2012). Regression Analysis of the Relationship between Urban Heat Island Effect and Urban Canopy Characteristics in a Mountainous City, Chongqing. Indoor + Built Environment, 21(6), 821–836. https://doi.org/10.1177/1420326X12461659

38. Deng, Zhang, S., & Jones, P. (2019). Analysing the relationship between urban form and urban heat island effect at a city-block scale. IOP Conference Series. Earth and Environmental Science, 329(1), 12045–. https://doi.org/10.1088/1755-1315/329/1/012045

39. Romano, Prataviera, E., Carnieletto, L., Vivian, J., Zinzi, M., & Zarrella, A. (2021). Assessment of the Urban Heat Island Impact on Building Energy Performance at District Level with the EUReCA Platform. Climate (Basel), 9(3), 48–. https://doi.org/10.3390/cli9030048

40. Li, Liu, Z., Nan, Y., Li, S., & Yang, Y. (2018). Comparative Analysis of Urban Heat Island Intensities in Chinese, Russian, and DPRK Regions across the Transnational Urban Agglomeration of the Tumen River in Northeast Asia. Sustainability (Basel, Switzerland), 10(8), 2637–. https://doi.org/10.3390/su10082637

41. Lee, Kim, J. T., & Lee, M. G. (2014). Mitigation of urban heat island effect and greenroofs. Indoor + Built Environment, 23(1), 62–69. https://doi.org/10.1177/1420326X12474483

42. Helmholz, Bulatov, D., Kottler, B., Burton, P., Mancini, F., May, M., Strauß, E., & Hecht, M. (2021). QUANTIFYING THE IMPACT OF URBAN INFILL ON THE URBAN HEAT ISLAND EFFECT – A CASE STUDY FOR AN ALTERNATIVE MEDIUM DENSITY MODEL. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences., XLVI-4/W1-2021, 43–50. https://doi.org/10.5194/isprs-archives-XLVI-4-W1-2021-43-2021

43. Shahmohamadi, Che-Ani, A. I., Maulud, K. N. A., Sairi, A., & Mohd-Nor, M. F. I. (2010). The Framework to Mitigate the Urban Heat Island Effect for Improving Environment and Protecting Human Health. International Journal of Sustainable Development and Planning, 5(4), 351–366. https://doi.org/10.2495/SDP-V5-N4-351-366

44. Serpil Önder, & Ahmet Akay. (2014). The Roles of Plants on Mitigating the Urban Heat Islands' Negative Effects. International Journal of Agriculture and Economic Development, 2(2), 18–.

45. Stevovic, Mirjanic, D., & Djuric, N. (2018). Theory and smart practice in the reduction of negative effects of urban heat island. Thermal Science, 22(Suppl. 4), 1011–1031. https://doi.org/10.2298/TSCI170530128S

46. Jørgensen, Kjærgaard, M., Lazarova-Molnar, S., Shaker, H., & Veje, C. (2015). Challenge: Advancing Energy Informatics to Enable Assessable Improvements of Energy Performance in Buildings. Proceedings of the 2015 ACM Sixth International Conference on Future Energy Systems, 77–82. https://doi.org/10.1145/2768510.2770935

47. Andersen, Kolb, J., Chen, K., Fierro, G., Culler, D., & Katz, R. (2018). Democratizing Authority in the Built Environment. ACM Transactions on Sensor Networks, 14(3-4), 1–26. https://doi.org/10.1145/3199665

48. Hafeez, Chandio, Y., Bakar, A., Ali, A., Syed, A., Jadoon, T., & Alizai, M. (2017). Inverting HVAC for energy efficient thermal comfort in populous emerging countries. Proceedings of the 4th ACM International Conference on Systems for Energy-Efficient Built Environments, 1–10. https://doi.org/10.1145/3137133.3137137

49. Rashid, Mammen, P., Singh, S., Ramamritham, K., Singh, P., & Shenoy, P. (2017). Want to reduce energy consumption?: don't depend on the consumers. Proceedings of the 4th ACM International Conference on Systems for Energy-Efficient Built Environments, 1–4. https://doi.org/10.1145/3137133.3137164

50. Xiaoqi Chen, Chandrasekaran, R., Fengyi Song, & Xiaofan Jiang. (2016). Poster Abstract: Personal Energy Footprint in Shared Building Environment. 2016 15th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), 1–2. https://doi.org/10.1109/IPSN.2016.7460710

51. Shahata, & Zayed, T. (2008). Simulation as a tool for life cycle cost analysis. Proceedings of the 40th Conference on Winter Simulation, 2497–2503. https://doi.org/10.1109/WSC.2008.4736359

52. Dawood, Lord, R., & Dawood, N. (2009). Development of a visual whole life-cycle energy assessment framework for built environment. Proceedings of the 2009 Winter Simulation Conference (WSC), 2653–2663. https://doi.org/10.1109/WSC.2009.5429263

53. Ziyadi, & Al-Qadi, I. L. (2018). Model uncertainty analysis using data analytics for life-cycle assessment (LCA) applications. The International Journal of Life Cycle Assessment, 24(5), 945–959. https://doi.org/10.1007/s11367-018-1528-7

54. Kuznetsov, & Tomitsch, M. (2018). A Study of Urban Heat: Understanding the Challenges and Opportunities for Addressing Wicked Problems in HCI. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 1–13. https://doi.org/10.1145/3173574.3174137

55. Johansson, Gentile, N., & Neij, L. (2021). Energy efficiency behaviour in the built environment—an assessment of current evaluation practices in the Nordic countries. Energy Efficiency, 14(3). https://doi.org/10.1007/s12053-021-09938-z

56. Muhammad, Ibrahim, S. K., & Dalibi, S. G. (2020). Barriers and Drivers Facing Architects in Adopting Energy Efficiency and the use of Zero-carbon Technologies in Nigerian Built Environment. IOP Conference Series. Earth and Environmental Science, 588(2), 22046–. https://doi.org/10.1088/1755-1315/588/2/022046

57. Çimen. (2021). Construction and built environment in circular economy: A comprehensive literature review. Journal of Cleaner Production, 305, 127180–. https://doi.org/10.1016/j.jclepro.2021.127180

58. Mao, Bao, Y., Huang, Z., Liu, Q., & Liu, G. (2020). High-Resolution Mapping of the Urban Built Environment Stocks in Beijing. Environmental Science & Technology, 54(9), 5345–5355. https://doi.org/10.1021/acs.est.9b07229

59. Ming Hu; A Review of Life Cycle Research of the Built Environment At Difference Scales: a Citation Analysis Using Big Data. Journal of Green Building 1 June 2019; 14 (3): 63–80. doi: https://doi.org/10.3992/1943-4618.14.3.63

60. Pearlmutter, Pucher, B., Calheiros, C. S. C., Hoffmann, K. A., Aicher, A., Pinho, P., Stracqualursi, A., Korolova, A., Pobric, A., Galvão, A., Tokuç, A., Bas, B., Theochari, D., Milosevic, D., Giancola, E., Bertino, G., Castellar, J. A. C., Flaszynska, J., Onur, M., … Nehls, T. (2021). Closing Water Cycles in the Built Environment through Nature-Based Solutions: The Contribution of Vertical Greening Systems and Green Roofs. Water (Basel), 13(16), 2165–. https://doi.org/10.3390/w13162165

61. Wang Yue, Tian Yiwei, Ge Jian, & Xu Ying. (2011). The study on the status of energy consumption and energy-efficiency management of new rural residential buildings in Hangzhou, China. 2011 International Conference on Business Management and Electronic Information, 2, 49–52. https://doi.org/10.1109/ICBMEI.2011.5917840

62. Chuanhong Zhang, & Huixi Xu. (2013). Study on the evolution tendency of the urban heat island effect in Xichang City using Remote Sensing. 2013 21st International Conference on Geoinformatics, 1–4. https://doi.org/10.1109/Geoinformatics.2013.6626172

63. Adinyira, Kwofie, T. E., & Quarcoo, F. (2017). Stakeholder requirements for building energy efficiency in mass housing delivery: the House of Quality approach. Environment, Development and Sustainability, 20(3), 1115–1131. https://doi.org/10.1007/s10668-017-9930-z

64. Alajmi, Short, A., Ferguson, J., Poel, K. V., & Griffin, C. (2020). Detailed energy efficiency strategies for converting an existing office building to NZEB: a case study in the Pacific Northwest. Energy Efficiency, 13(6), 1089–1104. https://doi.org/10.1007/s12053-020-09861-9

References – Built Environment

65. Romero, Hari, K. ., Cordero, I., Jeonghui Min, & Rojas-Solorzano, L. (2016). Viability of energy efficiency measures in resort buildings - Case study: Mazatlan, Mexico. 4th IET Clean Energy and Technology Conference (CEAT 2016), 27–. https://doi.org/10.1049/cp.2016.1284

66. Kakoniti, Georgiou, G., Marakkos, K., Kumar, P., & Neophytou, M. K.-A. (2015). The role of materials selection in the urban heat island effect in dry mid-latitude climates. Environmental Fluid Mechanics (Dordrecht, Netherlands : 2001), 16(2), 347–371. https://doi.org/10.1007/s10652-015-9426-z

67. Li, Zhang, X., Zhu, S., Wang, X., Lu, Y., Du, S., & Shi, X. (2020). Transformation of Urban Surfaces and Heat Islands in Nanjing during 1984–2018. Sustainability (Basel, Switzerland), 12(16), 6521–. https://doi.org/10.3390/su12166521

68. Gonçalves, Ornellas, G., Castro Ribeiro, A., Maia, F., Rocha, A., & Feliciano, M. (2018). Urban Cold and Heat Island in the City of Bragança (Portugal). Climate (Basel), 6(3), 70–. https://doi.org/10.3390/cli6030070

69. Biju, Sarkar, C., & Prasad, R. (2017). An energy-harvesting facade optimization system for built environments. Proceedings of the 4th ACM International Conference on Systems for Energy-Efficient Built Environments, 1–2. https://doi.org/10.1145/3137133.3141442

70. Januszkiewicz, & Alagoz, M. (2020). Inspired by Nature: The Sun and Shadow Pavilion, Social Integration and Energy Saving in the Built Environment. IOP Conference Series. Materials Science and Engineering, 960(4), 42081–. https://doi.org/10.1088/1757-899X/960/4/042081

71. Zhang, Yan, F., Liu, H., & Qiao, Z. (2021). Towards low carbon cities: A machine learning method for predicting urban blocks carbon emissions (UBCE) based on built environment factors (BEF) in Changxing City, China. Sustainable Cities and Society, 69, 102875–. https://doi.org/10.1016/j.scs.2021.102875

72. Tu Peng, Zi Xu, & Yu Liang. (2020). Constructing an Environmental Friendly Low-Carbon-Emission Intelligent Transportation System Based on Big Data and Machine Learning Methods. Sustainability (Basel, Switzerland), 12(19), 8118–. https://doi.org/10.3390/su12198118

73. Park, Ha, J., & Lee, S. (2017). Association between Three-Dimensional Built Environment and Urban Air Temperature: Seasonal and Temporal Differences. Sustainability (Basel, Switzerland), 9(8), 1338–. https://doi.org/10.3390/su9081338

74. Johansson, Gentile, N., & Neij, L. (2021). Energy efficiency behaviour in the built environment—an assessment of current evaluation practices in the Nordic countries. Energy Efficiency, 14(3). https://doi.org/10.1007/s12053-021-09938-z

75. Oikonomou, & van der Gaast, W. (2008). Integrating Joint Implementation Projects for Energy Efficiency on the Built Environment with White Certificates in The Netherlands. Mitigation and Adaptation Strategies for Global Change, 13(1), 61–85. https://doi.org/10.1007/s11027-007-9081-x

76. Hodorog, Petri, I., Rezgui, Y., & Hippolyte, J.-L. (2020). Building information modelling knowledge harvesting for energy efficiency in the Construction industry. Clean Technologies and Environmental Policy, 23(4), 1215–1231. https://doi.org/10.1007/s10098-020-02000-z

77. Moreno, Dufour, L., Skarmeta, A. F., Jara, A. J., Genoud, D., Ladevie, B., & Bezian, J.-J. (2015). Big data: the key to energy efficiency in smart buildings. Soft Computing (Berlin, Germany), 20(5), 1749–1762. https://doi.org/10.1007/s00500-015-1679-4

78. Judkoff. (2008). Increasing Building Energy Efficiency Through Advances in Materials. MRS Bulletin, 33(4), 449–454. https://doi.org/10.1557/mrs2008.88

79. Hu, & Qiu, Y. (2018). A comparison of building energy codes and policies in the USA, Germany, and China: progress toward the net-zero building goal in three countries. Clean Technologies and Environmental Policy, 21(2), 291–305. https://doi.org/10.1007/s10098-018-1636-x

80. Jiaping Liu, Runshan Wang, Rongrong Hu, Liu Yang, & Dalong Liu. (2010). Energy efficiency of rural residential buildings: a sustainable case study in Daping Village, Sichuan Province. Frontiers of Energy and Power Engineering in China, 4(1), 117–. https://doi.org/10.1007/s11708-009-0081-2

81. Oikonomou, & van der Gaast, W. (2008). Integrating Joint Implementation Projects for Energy Efficiency on the Built Environment with White Certificates in The Netherlands. Mitigation and Adaptation Strategies for Global Change, 13(1), 61–85. https://doi.org/10.1007/s11027-007-9081-x

82. Oikonomou, & van der Gaast, W. (2008). Integrating Joint Implementation Projects for Energy Efficiency on the Built Environment with White Certificates in The Netherlands. Mitigation and Adaptation Strategies for Global Change, 13(1), 61–85. https://doi.org/10.1007/s11027-007-9081-x

83. Billio, Costola, M., Pelizzon, L., & Riedel, M. (2021). Buildings' Energy Efficiency and the Probability of Mortgage Default: The Dutch Case. The Journal of Real Estate Finance and Economics. https://doi.org/10.1007/s11146-021-09838-0

84. Paone, & Bacher, J.-P. (2018). The Impact of Building Occupant Behavior on Energy Efficiency and Methods to Influence It: A Review of the State of the Art. Energies (Basel), 11(4), 953–. https://doi.org/10.3390/en11040953

85. Eslamnoor, & Vural, S. M. (2021). User behavior and energy efficiency in north cyprus university dormitories: a case study. Journal of Housing and the Built Environment. https://doi.org/10.1007/s10901-021-09878-1

86. Ye, Hinkelman, K., Lou, Y., Zuo, W., Wang, G., & Zhang, J. (2021). Evaluating the energy impact potential of energy efficiency measures for retrofit applications: A case study with U.S. medium office buildings. Building Simulation, 14(5), 1377–1393. https://doi.org/10.1007/s12273-021-0765-z

87. Ye, Hinkelman, K., Lou, Y., Zuo, W., Wang, G., & Zhang, J. (2021). Evaluating the energy impact potential of energy efficiency measures for retrofit applications: A case study with U.S. medium office buildings. Building Simulation, 14(5), 1377–1393. https://doi.org/10.1007/s12273-021-0765-z

88. Mekhilef, Saidur, R., Said, S. M., Hong, P. H., & Islam, M. R. (2013). Techno-economic evaluation of energy efficiency measures in high rise residential buildings in Malaysia. Clean Technologies and Environmental Policy, 16(1), 23–35. https://doi.org/10.1007/s10098-013-0587-5

89. de Melo, & de Martino Jannuzzi, G. (2015). Cost-effectiveness of CO2 emissions reduction through energy efficiency in Brazilian building sector. Energy Efficiency, 8(4), 815–826. https://doi.org/10.1007/s12053-014-9322-2

90. Palmer, & Walls, M. (2016). Using information to close the energy efficiency gap: a review of benchmarking and disclosure ordinances. Energy Efficiency, 10(3), 673–691. https://doi.org/10.1007/s12053-016-9480-5

91. Reinisch, Kofler, M., Iglesias, F., & Kastner, W. (2010). ThinkHome Energy Efficiency in Future Smart Homes. EURASIP Journal on Embedded Systems, 2011(1), 1–18. https://doi.org/10.1155/2011/104617

92. Tadeu, Tadeu, A., Simões, N., Gonçalves, M., & Prado, R. (2018). A sensitivity analysis of a cost optimality study on the energy retrofit of a single-family reference building in Portugal. Energy Efficiency, 11(6), 1411–1432. https://doi.org/10.1007/s12053-018-9645-5

93. Teng, Wang, W., Mu, X., & Xu, C. (2020). Assessing energy efficiency of green measures for residential buildings: the simulation case of the Changchun city in China. Journal of Housing and the Built Environment, 36(3), 1103–1117. https://doi.org/10.1007/s10901-020-09793-x

94. Le, & Paris, H. (2018). A life cycle assessment-based approach for evaluating the influence of total build height and batch size on the environmental performance of electron beam melting. International Journal of Advanced Manufacturing Technology, 98(1-4), 275–288. https://doi.org/10.1007/s00170-018-2264-7

95. Aktas, & Bilec, M. M. (2011). Service life prediction of residential interior finishes for life cycle assessment. The International Journal of Life Cycle Assessment, 17(3), 362–371. https://doi.org/10.1007/s11367-011-0367-6

96. Collins. (2010). Inclusion of carbonation during the life cycle of built and recycled concrete: influence on their carbon footprint. The International Journal of Life Cycle Assessment, 15(6), 549–556. https://doi.org/10.1007/s11367-010-0191-4

97. Vilcekova, & Kridlova Burdova, E. (2014). Multi-criteria analysis of building assessment regarding energy performance using a life-cycle approach. International Journal of Energy and Environmental Engineering, 5(2-3), 1–9. https://doi.org/10.1007/s40095-014-0083-7

98. Günkaya, Özkan, A., & Banar, M. (2020). The effect of energy-saving options on environmental performance of a building: a combination of energy audit–life cycle assessment for a university building. Environmental Science and Pollution Research International, 28(7), 8822–8832. https://doi.org/10.1007/s11356-020-11141-z

99. Balasbaneh, & Sher, W. (2021). Life cycle sustainability assessment analysis of different concrete construction techniques for residential building in Malaysia. The International Journal of Life Cycle Assessment, 26(7), 1301–1318. https://doi.org/10.1007/s11367-021-01938-6

References – Built Environment

100. Hoxha, Maierhofer, D., Saade, M. R. ., & Passer, A. (2021). Influence of technical and electrical equipment in life cycle assessments of buildings: case of a laboratory and research building. The International Journal of Life Cycle Assessment, 26(5), 852–863. https://doi.org/10.1007/s11367-021-01919-9

101. Dwaikat, & Ali, K. N. (2018). Green buildings life cycle cost analysis and life cycle budget development: Practical applications. Journal of Building Engineering, 18, 303–311. https://doi.org/10.1016/j.jobe.2018.03.015

102. Vavanou, Schwartz, Y., & Mumovic, D. (2021). The life cycle impact of refurbishment packages on residential buildings with different initial thermal conditions. Journal of Housing and the Built Environment. https://doi.org/10.1007/s10901-021-09871-8

103. Dong, & Ng, S. T. (2015). A social life cycle assessment model for building construction in Hong Kong. The International Journal of Life Cycle Assessment, 20(8), 1166–1180. https://doi.org/10.1007/s11367-015-0908-5

104. Kakoniti, Georgiou, G., Marakkos, K., Kumar, P., & Neophytou, M. K.-A. (2015). The role of materials selection in the urban heat island effect in dry mid-latitude climates. Environmental Fluid Mechanics (Dordrecht, Netherlands : 2001), 16(2), 347–371. https://doi.org/10.1007/s10652-015-9426-z

105. Ma, Zhang, L., Guo, M., & Zhao, J. (2021). The effect of various urban design parameter in alleviating urban heat island and improving thermal health—a case study in a built pedestrianized block of China. Environmental Science and Pollution Research International, 28(28), 38406–38425. https://doi.org/10.1007/s11356-021-13179-z

106. Erdem, Cubukcu, K. M., & Sharifi, A. (2020). An analysis of urban form factors driving Urban Heat Island: the case of Izmir. Environment, Development and Sustainability, 23(5), 7835–7859. https://doi.org/10.1007/s10668-020-00950-4

107. Abulibdeh. (2021). Analysis of urban heat island characteristics and mitigation strategies for eight arid and semi-arid gulf region cities. Environmental Earth Sciences, 80(7), 259–259. https://doi.org/10.1007/s12665-021-09540-7"

108. Guindon, & Nirupama, N. (2015). Reducting risk from urban heat island effects in cities. Natural Hazards (Dordrecht), 77(2), 823–831. https://doi.org/10.1007/s11069-015-1627-8

109. Ünal, Sonuç, C. Y., Incecik, S., Topcu, H. S., Diren-Üstün, D. H., & Temizöz, H. P. (2019). Investigating urban heat island intensity in Istanbul. Theoretical and Applied Climatology, 139(1-2), 175–190. https://doi.org/10.1007/s00704-019-02953-2

110. Buo, Sagris, V., Burdun, I., & Uuemaa, E. (2020). Estimating the expansion of urban areas and urban heat islands (UHI) in Ghana: a case study. Natural Hazards (Dordrecht), 105(2), 1299–1321. https://doi.org/10.1007/s11069-020-04355-4

111. Cai, Zhang, H., Zheng, P., & Pan, W. (2016). Quantifying the Impact of Land use/Land Cover Changes on the Urban Heat Island: A Case Study of the Natural Wetlands Distribution Area of Fuzhou City, China. Wetlands (Wilmington, N.C.), 36(2), 285–298. https://doi.org/10.1007/s13157-016-0738-7

112. Connors, Galletti, C. S., & Chow, W. T. L. (2012). Landscape configuration and urban heat island effects: assessing the relationship between landscape characteristics and land surface temperature in Phoenix, Arizona. Landscape Ecology, 28(2), 271–283. https://doi.org/10.1007/s10980-012-9833-1

113. Corumluoglu, & Asri, I. (2014). The effect of urban heat island on Izmir’s city ecosystem and climate. Environmental Science and Pollution Research International, 22(5), 3202–3211. https://doi.org/10.1007/s11356-014-2874-z

114. The impact of heat waves on surface urban heat island and local economy in Cluj-Napoca city, Romania"

115. Liang, Ji, X., Guo, N., & Meng, L. (2021). Assessment of urban heat islands for land use based on urban planning: a case study in the main urban area of Xuzhou City, China. Environmental Earth Sciences, 80(8). https://doi.org/10.1007/s12665-021-09588-5

116. Shahfahad, Talukdar, S., Rihan, M., Hang, H. T., Bhaskaran, S., & Rahman, A. (2021). Modelling urban heat island (UHI) and thermal field variation and their relationship with land use indices over Delhi and Mumbai metro cities. Environment, Development and Sustainability, 24(3), 3762–3790. https://doi.org/10.1007/s10668-021-01587-7

117. Xiong, & Zhang, F. (2021). Effect of human settlements on urban thermal environment and factor analysis based on multi-source data: A case study of Changsha city. Journal of Geographical Sciences, 31(6), 819–838. https://doi.org/10.1007/s11442-021-1873-5

118. Gardezi, Shafiq, N., & Khan, M. W. A. (2021). Relational pre-impact assessment of conventional housing features and carbon footprint for achieving sustainable built environment. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-021-01793-3

119. Wu, & Su, D. (2021). LCA of an industrial luminaire using product environmental footprint method. Journal of Cleaner Production, 305, 127159–. https://doi.org/10.1016/j.jclepro.2021.127159

120. Hafez, Kurda, R., Al-Ayish, N., Garcia-Segura, T., Cheung, W. M., & Nagaratnam, B. (2021). A whole life cycle performance-based ECOnomic and ECOlogical assessment framework (ECO2) for concrete sustainability. Journal of Cleaner Production, 292, 126060–. https://doi.org/10.1016/j.jclepro.2021.126060

121. Du, Han, X., Li, Y., Li, Z., Xia, B., & Guo, X. (2021). The energy rebound effect of residential buildings: Evidence from urban and rural areas in China. Energy Policy, 153, 112235–. https://doi.org/10.1016/j.enpol.2021.112235

122. Azmi, Arıcı, M., & Baharun, A. (2021). A review on the factors influencing energy efficiency of mosque buildings. Journal of Cleaner Production, 292, 126010–. https://doi.org/10.1016/j.jclepro.2021.126010

123. Gardezi, Shafiq, N., & Khan, M. W. A. (2021). Relational pre-impact assessment of conventional housing features and carbon footprint for achieving sustainable built environment. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-021-01793-3

124. Kamruzzaman, Deilami, K., & Yigitcanlar, T. (2018). Investigating the urban heat island effect of transit oriented development in Brisbane. Journal of Transport Geography, 66, 116–124. https://doi.org/10.1016/j.jtrangeo.2017.11.016

125. Lou, Yang, Y., Ye, Y., Zuo, W., & Wang, J. (2021). The effect of building retrofit measures on CO2 emission reduction – A case study with U.S. medium office buildings. Energy and Buildings, 253, 111514–. https://doi.org/10.1016/j.enbuild.2021.111514

126. Anand, & Amor, B. (2017). Recent developments, future challenges and new research directions in LCA of buildings: A critical review. Renewable & Sustainable Energy Reviews, 67, 408–416. https://doi.org/10.1016/j.rser.2016.09.058

127. Chukwuka Christian Ohueri, Wallace Imoudu Enegbuma, & Russell Kenley. (2018). Energy efficiency practices for Malaysian green office building occupants. Built Environment Project and Asset Management, 8(2), 134–146. https://doi.org/10.1108/BEPAM-10-2017-0091

128. Zhang, Tan, S., Lei, Y., & Wang, S. (2013). Life cycle assessment of a single-family residential building in Canada: A case study. Building Simulation, 7(4), 429–438. https://doi.org/10.1007/s12273-013-0159-y

129. Paleari, Lavagna, M., & Campioli, A. (2016). The assessment of the relevance of building components and life phases for the environmental profile of nearly zero-energy buildings: life cycle assessment of a multifamily building in Italy. The International Journal of Life Cycle Assessment, 21(12), 1667–1690. https://doi.org/10.1007/s11367-016-1133-6

130. Bhochhibhoya, Pizzol, M., Achten, W. M. ., Maskey, R. K., Zanetti, M., & Cavalli, R. (2017). Comparative life cycle assessment and life cycle costing of lodging in the Himalaya. The International Journal of Life Cycle Assessment, 22(11), 1851–1863. https://doi.org/10.1007/s11367-016-1212-8

References – Built Environment

131. Collinge, Landis, A. E., Jones, A. K., Schaefer, L. A., & Bilec, M. M. (2012). Dynamic life cycle assessment: framework and application to an institutional building. The International Journal of Life Cycle Assessment, 18(3), 538–552. https://doi.org/10.1007/s11367-012-0528-2

132. Atasoy. (2019). Assessing the impacts of land-use/land-cover change on the development of urban heat island effects. Environment, Development and Sustainability, 22(8), 7547–7557. https://doi.org/10.1007/s10668-019-00535-w

133. Memon, Leung, D. Y. C., Liu, C.-H., & Leung, M. K. H. (2010). Urban heat island and its effect on the cooling and heating demands in urban and suburban areas of Hong Kong. Theoretical and Applied Climatology, 103(3-4), 441–450. https://doi.org/10.1007/s00704-010-0310-y

134. Zeng, Huang, W., Zhan, F., Zhang, H., & Liu, H. (2010). Study on the Urban Heat Island Effects and Its Relationship with Surface Biophysical Characteristics Using MODIS Imageries. Geo-Spatial Information Science, 13(1), 1–7. https://doi.org/10.1007/s11806-010-0204-2

135. Zhang, Wang, Z., & Sun, Y. (2009). Analysis of urban heat island effect using an improved CTTC and STTC model. Transactions of Tianjin University, 15(3), 201–205. https://doi.org/10.1007/s12209-009-0035-0

136. Zaid, Zaid, L. M., Esfandiari, M., & Abu Hasan, Z. F. (2021). Green roof maintenance for non-residential buildings in tropical climate: case study of Kuala Lumpur. Environment, Development and Sustainability, 24(2), 2471–2496. https://doi.org/10.1007/s10668-021-01542-6

137. Hong, Xu, Y., Sun, K., Zhang, W., Luo, X., & Hooper, B. (2021). Urban microclimate and its impact on building performance: A case study of San Francisco. Urban Climate, 38(C), 100871–. https://doi.org/10.1016/j.uclim.2021.100871

138. Sherman, Naganathan, H., & Parrish, K. (2021). Energy Savings Results from Small Commercial Building Retrofits in the US. Energies (Basel), 14(19), 6207–. https://doi.org/10.3390/en14196207

139. Hay, & Ostertag, C. P. (2018). Life cycle assessment (LCA) of double-skin façade (DSF) system with fiber-reinforced concrete for sustainable and energy-efficient buildings in the tropics. Building and Environment, 142, 327–341. https://doi.org/10.1016/j.buildenv.2018.06.024

140. Pacheco-Torgal. (2017). High tech startup creation for energy efficient built environment. Renewable & Sustainable Energy Reviews, 71, 618–629. https://doi.org/10.1016/j.rser.2016.12.088

141. Ramírez-Villegas, Eriksson, O., & Olofsson, T. (2019). Life Cycle Assessment of Building Renovation Measures–Trade-off between Building Materials and Energy. Energies (Basel), 12(3), 344–. https://doi.org/10.3390/en12030344

142. Orr, Bras, A., & Ibell, T. (2017). Effectiveness of design codes for life cycle energy optimisation. Energy and Buildings, 140, 61–67. https://doi.org/10.1016/j.enbuild.2017.01.085

143. Balaras, Droutsa, K. G., Dascalaki, E. G., Kontoyiannidis, S., Moro, A., & Bazzan, E. (2019). Urban Sustainability Audits and Ratings of the Built Environment. Energies (Basel), 12(22), 4243–. https://doi.org/10.3390/en12224243

144. Wang, Liu, H., Miao, S., Wu, Q., Zhang, N., & Qiao, F. (2020). Effectiveness of Urban Hydrological Processes in Mitigating Urban Heat Island and Human Thermal Stress During a Heat Wave Event in Nanjing, China. Journal of Geophysical Research. Atmospheres, 125(24). https://doi.org/10.1029/2020JD033275

145. Chen, & You, X. (2019). Reduction of urban heat island and associated greenhouse gas emissions. Mitigation and Adaptation Strategies for Global Change, 25(4), 689–711. https://doi.org/10.1007/s11027-019-09886-1

146. Pigliautile, Chàfer, M., Pisello, A. L., Pérez, G., & Cabeza, L. F. (2020). Inter-building assessment of urban heat island mitigation strategies: Field tests and numerical modelling in a simplified-geometry experimental set-up. Renewable Energy, 147, 1663–1675. https://doi.org/10.1016/j.renene.2019.09.082

147. Forsythe, & Wilkinson, S. (2015). Measuring office fit-out changes to determine recurring embodied energy in building life cycle assessment. Facilities (Bradford, West Yorkshire, England), 33(3/4), 262–274. https://doi.org/10.1108/F-08-2013-0065

148. Schwartz, Yair et al. “Multi-objective genetic algorithms for the minimisation of the life cycle carbon footprint and life cycle cost of the refurbishment of a residential complex's envelope: a case study.” SpringSim (2015).

149. Liang, Gu, H., & Bergman, R. (2021). Environmental Life-Cycle Assessment and Life-Cycle Cost Analysis of a High-Rise Mass Timber Building: A Case Study in Pacific Northwestern United States. Sustainability (Basel, Switzerland), 13(14), 7831–. https://doi.org/10.3390/su13147831

150. Rajagopalan, Brancart, S., De Regel, S., Paduart, A., Temmerman, N. D., & Debacker, W. (2021). Multi-Criteria Decision Analysis Using Life Cycle Assessment and Life Cycle Costing in Circular Building Design: A Case Study for Wall Partitioning Systems in the Circular Retrofit Lab. Sustainability (Basel, Switzerland), 13(9), 5124–. https://doi.org/10.3390/su13095124

151. Pelenur, & Cruickshank, H. J. (2012). Closing the Energy Efficiency Gap: A study linking demographics with barriers to adopting energy efficiency measures in the home. Energy (Oxford), 47(1), 348–357. https://doi.org/10.1016/j.energy.2012.09.058

152. Karin Regina de Casas Castro Marins. (2014). A method for energy efficiency assessment during urban energy planning. Smart and Sustainable Built Environment, 3(2), 132–. https://doi.org/10.1108/SASBE-12-2013-0056

153. Raj, Meena, C. S., Agarwal, N., Saini, L., Hussain Khahro, S., Subramaniam, U., & Ghosh, A. (2021). A Review on Numerical Approach to Achieve Building Energy Efficiency for Energy, Economy and Environment (3E) Benefit. Energies (Basel), 14(15), 4487–. https://doi.org/10.3390/en14154487

154. Moayedi, Amila Wan Abdullah Zawawi, N., & Shahir Liew, M. (2019). Building life cycle analysis toward low carbon emission and energy efficiency. IOP Conference Series. Earth and Environmental Science, 220(1), 12054–. https://doi.org/10.1088/1755-1315/220/1/012054

155. Udale Hussaini, & Hanita Abdul Majid, N. (2014). Human behaviour in household energy use and the implications of energy efficiency delivery: A case of Bauchi, Nigeria. International Journal of Energy Sector Management, 8(2), 230–239. https://doi.org/10.1108/IJESM-10-2013-0005

156. Cadelano, Cicolin, F., Emmi, G., Mezzasalma, G., Poletto, D., Galgaro, A., & Bernardi, A. (2019). Improving the Energy Efficiency, Limiting Costs and Reducing CO2 Emissions of a Museum Using Geothermal Energy and Energy Management Policies. Energies (Basel), 12(16), 3192–. https://doi.org/10.3390/en12163192

157. Petri, Kubicki, S., Rezgui, Y., Guerriero, A., & Li, H. (2017). Optimizing Energy Efficiency in Operating Built Environment Assets through Building Information Modeling: A Case Study. Energies (Basel), 10(8), 1167–. https://doi.org/10.3390/en10081167

158. Meng, Zhang, L., Sun, Z., Meng, F., Wang, L., & Sun, Y. (2018). Characterizing spatial and temporal trends of surface urban heat island effect in an urban main built-up area: A 12-year case study in Beijing, China. Remote Sensing of Environment, 204, 826–837. https://doi.org/10.1016/j.rse.2017.09.019

159. Huang, & Chen, L.-C. (2020). A Numerical Study on Mitigation Strategies of Urban Heat Islands in a Tropical Megacity: A Case Study in Kaohsiung City, Taiwan. Sustainability (Basel, Switzerland), 12(10), 3952–. https://doi.org/10.3390/su12103952

160. Wonorahardjo, Sutjahja, I. M., Mardiyati, Y., Andoni, H., Thomas, D., Achsani, R. A., & Steven, S. (2019). Characterising thermal behaviour of buildings and its effect on urban heat island in tropical areas. International Journal of Energy and Environmental Engineering, 11(1), 129–142. https://doi.org/10.1007/s40095-019-00317-0

161. Wu, Zhang, L., & Zang, S. (2019). Examining seasonal effect of urban heat island in a coastal city. PloS One, 14(6), e0217850–e0217850. https://doi.org/10.1371/journal.pone.0217850

References – Built Environment

162. Sharma, Conry, P., Fernando, H. J. S., Hamlet, A. F., Hellmann, J. J., & Chen, F. (2016). Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: evaluation with a regional climate model. Environmental Research Letters, 11(6), 64004–. https://doi.org/10.1088/1748-9326/11/6/064004

163. Steeneveld, Koopmans, S., Heusinkveld, B. G., van Hove, L. W. A., & Holtslag, A. A. M. (2011). Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands. Journal of Geophysical Research: Atmospheres, 116(D20), 1FF–n/a. https://doi.org/10.1029/2011JD015988

164. Hirano, Ihara, T., Gomi, K., & Fujita, T. (2019). Simulation-Based Evaluation of the Effect of Green Roofs in Office Building Districts on Mitigating the Urban Heat Island Effect and Reducing CO2 Emissions. Sustainability (Basel, Switzerland), 11(7), 2055–. https://doi.org/10.3390/su11072055

165. Xue, Wang, Z., & Chen, Q. (2021). Multi-objective optimization of building design for life cycle cost and CO2 emissions: A case study of a low-energy residential building in a severe cold climate. Building Simulation, 15(1), 83–98. https://doi.org/10.1007/s12273-021-0796-5

166. AL-Nassar, Ruparathna, R., Chhipi-Shrestha, G., Haider, H., Hewage, K., & Sadiq, R. (2016). Sustainability assessment framework for low rise commercial buildings: life cycle impact index-based approach. Clean Technologies and Environmental Policy, 18(8), 2579–2590. https://doi.org/10.1007/s10098-016-1168-1

167. Kofoworola, & Gheewala, S. H. (2008). Environmental life cycle assessment of a commercial office building in Thailand. The International Journal of Life Cycle Assessment, 13(6), 498–511. https://doi.org/10.1007/s11367-008-0012-1

168. Wonorahardjo, Sutjahja, I. M., Mardiyati, Y., Andoni, H., Thomas, D., Achsani, R. A., & Steven, S. (2019). Characterising thermal behaviour of buildings and its effect on urban heat island in tropical areas. International Journal of Energy and Environmental Engineering, 11(1), 129–142. https://doi.org/10.1007/s40095-019-00317-0

169. Magli, Lodi, C., Lombroso, L., Muscio, A., & Teggi, S. (2014). Analysis of the urban heat island effects on building energy consumption. International Journal of Energy and Environmental Engineering, 6(1), 91–99. https://doi.org/10.1007/s40095-014-0154-9

170. Wilkinson, Sara & Carmichael, Marc & Khonasty, Richardo. (2021). Towards smart green wall maintenance and Wallbot technology. Property Management. ahead-of-print. 10.1108/PM-09-2020-0062.

171. O'Malley, Piroozfarb, P. A. ., Farr, E. R. ., & Gates, J. (2014). An Investigation into Minimizing Urban Heat Island (UHI) Effects: A UK Perspective. Energy Procedia, 62, 72–80. https://doi.org/10.1016/j.egypro.2014.12.368

172. Guo, Gao, Y., Zhuang, C., Heiselberg, P., Levinson, R., Zhao, X., & Shi, D. (2020). Optimization of cool roof and night ventilation in office buildings: A case study in Xiamen, China. Renewable Energy, 147(P1), 2279–2294. https://doi.org/10.1016/j.renene.2019.10.032

173. Vahmani, Sun, F., Hall, A., & Ban-Weiss, G. (2016). Investigating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California. Environmental Research Letters, 11(12), 124027–. https://doi.org/10.1088/1748-9326/11/12/124027

174. Costanzo, Evola, G., & Marletta, L. (2016). Energy savings in buildings or UHI mitigation? Comparison between green roofs and cool roofs. Energy and Buildings, 114, 247–255. https://doi.org/10.1016/j.enbuild.2015.04.053

175. Roman, O'Brien, T., Alvey, J. B., & Woo, O. (2016). Simulating the effects of cool roof and PCM (phase change materials) based roof to mitigate UHI (urban heat island) in prominent US cities. Energy (Oxford), 96, 103–117. https://doi.org/10.1016/j.energy.2015.11.082

176. Barozzi, & Pollastro, M. (2016). Assessment of the Impact of Cool Roofs in Temperate Climates through a Comparative Experimental Campaign in Outdoor Test Cells. Buildings (Basel), 6(4), 52–. https://doi.org/10.3390/buildings6040052

177. Pisello, Santamouris, M., & Cotana, F. (2013). Active cool roof effect: impact of cool roofs on cooling system efficiency. Advances in Building Energy Research, 7(2), 209–221. https://doi.org/10.1080/17512549.2013.865560

178. Hosseini, Lee, B., & Vakilinia, S. (2017). Energy performance of cool roofs under the impact of actual weather data. Energy and Buildings, 145, 284–292. https://doi.org/10.1016/j.enbuild.2017.04.006