THERMAL PERFORMANCE ASSESSMENT OF COOL ROOFS ON SUPERMARKETS THROUGH CASE ANALYSIS IN 13 CITIES

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Abstract:	

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Abstract

Purpose – The paper studies the use of cool roof technology in order to avoid unnecessary energy consumption in supermarkets. This will allow to reduce and even cancel the heat absorbed by the roofs, transferring it to the buildings and thus, creating more sustainable cities.

Design/methodology/approach – Thirteen real supermarkets with cool roofs were analysed in Australia, Canada, the United States and Spain. An analysis of so many supermarkets located in different parts of the world with different climatic zones has allowed an inductive analysis, obtaining real data of energy consumption associated with the air conditioning installations for a year with and without implementing the cool roof technology.

Findings – The paper provides insights on how the use of cool-roof managed to reduce the need for energy for heating, ventilating, and air conditioning by between 3.5% and 38%. Additionally, this technology reduces the annual generation of carbon dioxide (CO_2) emissions per square meter of supermarket up to 2.7 $kgCO_2/m^2$. It could be an economical technology to apply in new and old buildings with a period of average economic recovery of 4 years.

Research implications – Due to the chosen research approach, the research results may be generalisable. Therefore, researchers are encouraged to test proposals in construction with other uses.

Practical implications – The paper includes economic and environmental implications for the development of cool-roof technology and smooths the way for its implementation in order to increase energy efficiency in commercial buildings.

Originality/value – This paper is an innovative contribution to the application of cool-roof technology as a source of energy savings in commercial construction through the analysis of supermarkets located in different countries with different climate zones. This will help other researchers to advance in this field and facilitate the implementation of the technology.

Keywords

Cool roof; Energy efficiency; Thermal comfort; Supermarket; Sustainable cities.

1. Introduction

A smart sustainable city is defined as a city that meets the needs of its present inhabitants, without compromising the ability of other people or future generations to meet their needs. Thus, this, supported by information and communication technologies (ICT) (Höjer & Wangel, 2015) does not exceed local or planetary environmental limitations. The smart city model has been promoted as an ample instrument to manage aforementioned urban and environmental challenges (Yigitcanlar et al., 2019). The elevated air temperature of a city, urban heat island (UHI), increases heat and pollution-related mortality, reduces the habitats´comfort and elevates the mean and peak energy demand of buildings (Mirzaei, 2015). The urban microclimate is affected by several factors such as spatial planning, architectural design, vegetation as well as the antropogenic activity (Maragkogiannis et al., 2014). The internal heat load in commercial buildings in warm and hot climates is predominantly driven by solar heat gain through the roof, walls and floors (Jo et al., 2010; Suehrcke et al., 2008). Cool roofs are those that remain cool in the sun by minimizing solar absorption and maximizing thermal emission-lessen the flow of heat from the roof into the building reducing the need for space cooling energy in conditioned buildings. These may also increase the need for heating energy in cold climates though the heating energy penalties are low, since most of the heating is required during later hours with little or no sunshine (Akbari & Konopacki, 2004).

For a commercial building, the decrease in annual cooling load is typically much greater than the increase in annual heating load (Levinson & Akbari, 2010). As many of the supermarket buildings are single storey ´warehouse´ type buildings, their predominant heat load comes through the roof, and thus are well suited to benefit from cool roof technology (Seifhashemi et al., 2018). Supermarkets are the main retail channel, a consolidated and growing model. They are large energy users, consuming 3% of the total electric energy in developed countries (Tassou et al., 2007). Within the commercial sector, the entire supermarket type establishments have one of the highest rates of energy consumption per square meter in all commercial and industrial sectors (Ríos & Roqueñí, 2018). These establishments waste energy for long periods, Heating, Ventilation and Air Conditioning (HVAC) system consumes 8% of this energy and generate a large amount of greenhouse gas emissions associated with energy consumption. In the United Kingdom, emissions from retail food outlets amounted to 4 $MtCO_2$, which represented 1% of total greenhouse gas (GHG) emissions to the atmosphere (Tassou et al., 2010). These emissions contribute a fundamental cause of climate change. The problem of climate change has mobilized society favouring international agreements that have led to the appearance of legislation aimed at avoiding GHG emissions. The need to develop a suitable energy strategy in the commercial sector is reinforced by the increase in the costs of electricity, which meant a reduction in company benefits (Ríos, 2019). Sustainable development calls for the use of sustainable energy systems (Shortall et al., 2015). Reduction of cooling power needed to achieve thermal comfort in commercial buildings using non absorptive and reflective skin materials can mitigate the harmful effects of electricity consumption particularly from non renovables sources. For many countries, lower energy consumption leads to a reduction in their dependence on imported fuel, however for all countries it means the elimination of pollutants such as particulates and greenhouse gases (Ríos, 2019). Sustainable development requires the use of sustainable construction; therefore, the use of cool roofs has a triple interest: social, environmental and economical. It constitutes an opportunity to modernise the sector with more efficient construction systems in order to to increase the environmental commitment of the companies, meaning a competitive advantage and an opportunity to increase the economic benefit due to the savings in energy consumption (Ríos, 2015).

In this article, thirteen cases of cool roof use in North American, Canadian, Australian and Spanish supermarkets were analysed, revealing an efficient eco-friendly constructive method, pretending to serve as a reference to be less harmful to the supermarkets construction environment where it is possible to reduce the need for energy consumption. The thermal emittance value of the roof surfaces considered in the simulations was ε: 0.650-0.875 depending on the supermarket, with average value of 0.85. Fig. 1 shows the location of the supermarkets being 1: Darwin, 2: Brisbane, 3. Alice Springs, 4: Dubbo, 5: Sydney, 6: Melbourne, 7: Canberra, 8: Montreal, 9: Toronto, 10: Sacramento, 11: Madrid, 12: Barcelona and 13: Bilbao. The cheapest source of energy is the energy never used. The use of cool roof in the construction of supermarket buildings allows to increase the energetic efficiency of the edification, reducing the environmental impact that the energy consumption necessary to reduce the thermal loads required. However, only a low fraction of commercial buildings has cool roofs. Thus, there is a great capacity for the development and implementation of this technology.

Fig. 1. Supermarkets location map.

2. Material and case presentation

A systematic review of the existing literature in different databases for the period 2004-2019 was carried out. The first database used in the December 2018 search was the Web of Science (WoS), including Medline, SciELO Citation Index, KCI-Korean Journal Database, Current Contents Connect, Derwent Innovations Index and Russian Science Citation Index. The searches were conducted using as descriptors in the subject file, the term "cool roof" AND "supermarket", two articles was found. Then, the terms were changed using "cool roof" AND "retail", twenty articles were found. The search terms were again changed, using "coloured roof" AND "supermarket" and the result was zero articles. Finally, the terms "coloured roof" AND "retail" were used and two articles were obtained. In January 2019, the Scopus database was used to perform a new search, using the same terms used in WoS. With the descriptors "cool roof" AND "supermarket" four articles were found. Applying "cool roof" AND "retail" thirteen articles were shown. By using "coloured roof" AND "supermarket" zero results were obtained, with "coloured roof" AND "supermarket" one article. From these documents, a choice was carried out in which research, based on the following inclusion criteria was selected: 1º) studies whose objective was the application of cool roof technology in supermarkets; 2º) written in English or Spanish; 3º) access to the full text of the article was available. We have also analysed a work sponsored by the U.S. Environmental Protection Agency, which describes the "cooling energy savings potential of light-colored roofs for residential and commercial buildings in 11 U.S. Metropolitan Areas". A total of 4 articles were identified with the inclusion and exclusion criteria discussed. The process of bibliographic review is illustrated in Fig. 2. Furthermore, an original content to compare with the existing reviewed papers was included. For this purpose, three real supermarkets located in different climatic areas throughout Spain have been analysed.

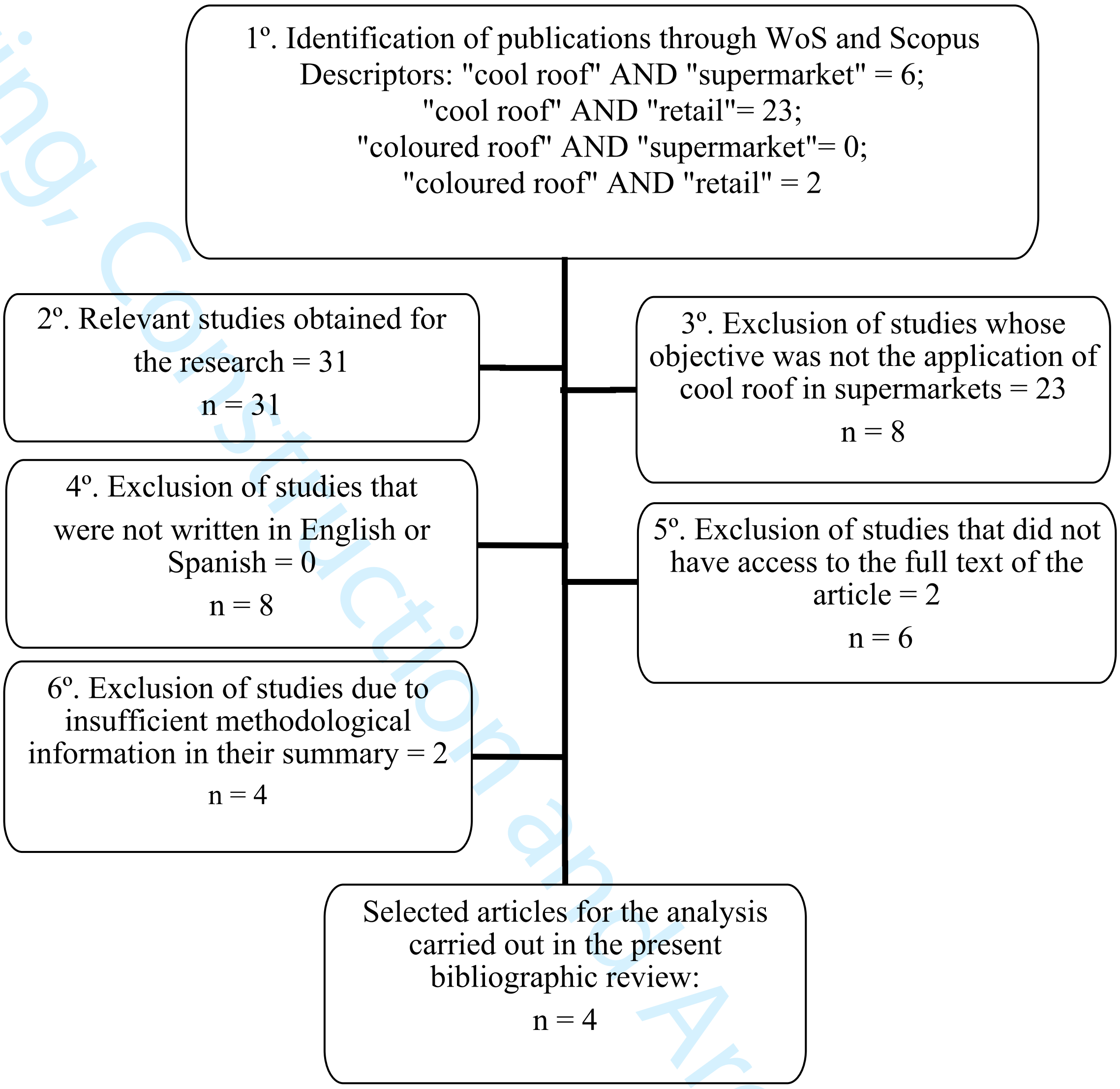


Fig. 2. Process of bibliographic review.

Fig. 3 represents the type of commercial building studied, being distributed in an independent building with a ground floor on which cool roof technology was applied.

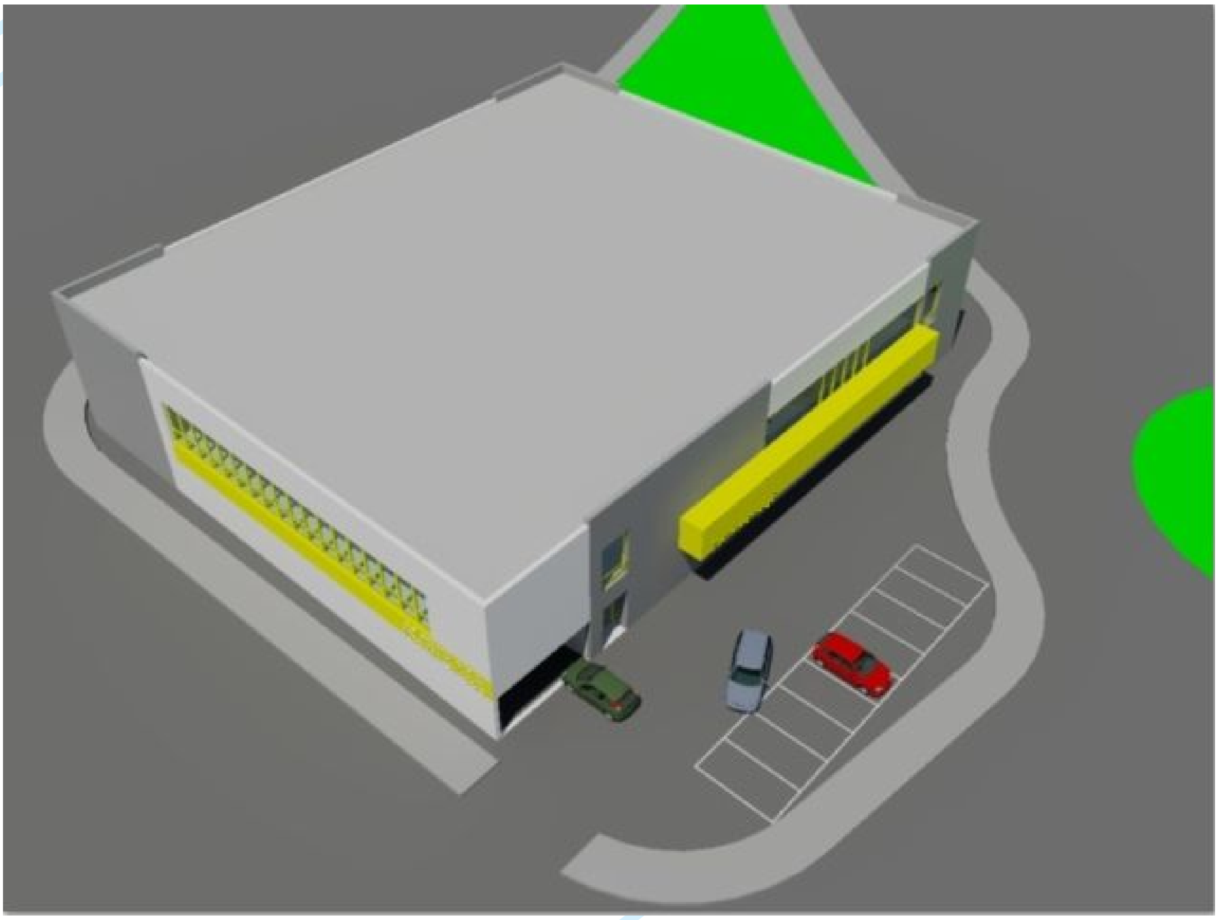
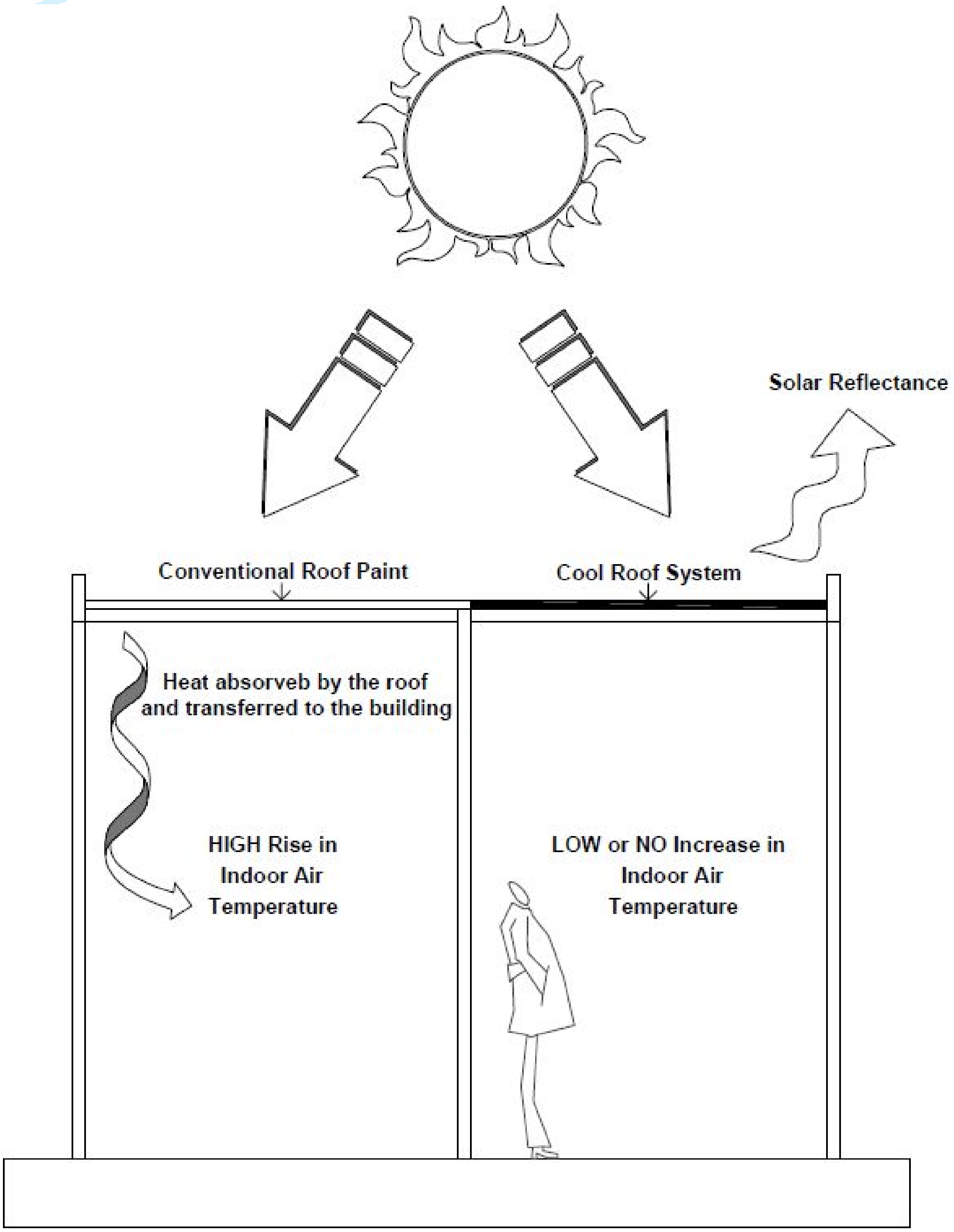


Fig. 3. Type of commercial building studied.

The real energy consumption in the thermal facilities of all supermarkets was analysed, by using both with and without cool roof technology. The values were obtained during periods of one year in order to consider the different seasonal climatological situations. The thermal characteristics of the supermarket cold roofs were also measured. With the values obtained, the savings in energy consumption and associated polluting emissions generated by the use of cool roofs were calculated. Additionally, the periods of return of the economic investment necessary to apply these Improvements were also evaluated. An analysis of so many supermarkets located in different parts of the world with different climatic zones has allowed an inductive analysis.

"Cool Roof" technology investigates and applies materials with a high Solar Reflectance Index (SRI). The higher the SRI index value, the greater the capacity of the surface to stay cool against insolation heating. Therefore, the greater the capacity to avoid unwanted heating inside buildings

142 exposed to insolation. Fig. 4 represents the thermal behaviour of a roof with and without a cool roof
143 coating against solar radiation.
144



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146 **Fig. 4.** Thermal behaviour of a roof with and without a cool roof coating against solar radiation.

147

2.1. Supermarkets with cool roof technology in Australia

The case study supermarket (model) is located in a single storey building dated 1990 with an area of 1002 m^2. It is located in the city of Brisbane (Queensland) which has a subtropical climate. The HVAC system are two roof mounted air conditioners. Table I shows the technical characteristics of the supermarket roof in Queensland. The energy efficiency potential of cool roof technology applied to similar retail buildings across Australia was extrapolated from the model through the examination of seven different locations, or climate zones (Seifhashemi et al., 2018). A virtual environment software by Integrated Environmental Solutions was used (IES-VE). Fig. 5 shows the locations of the Australian supermarkets, their types of climate and the average daily annual solar exposure by Australian Government (2019).

Table I. Technical characteristics of Brisbane (Queensland) supermarket roof.

Characteristics of the supermarket cool roof	
Material	Metal
Pitched	Low pitched (3.5%)
Thermal insulation of the roof	Reflective foil-backed bulk insulation blanket under roof sheeting
Cool roof coating used	Water based acrylic coating, specifically Shield coats Thermobond HRC (Artic White)
U-value (Thermal transmittance)	1.97 (W/m^2K)
Solar reflectance (without cool roof)	0.2
Solar reflectance (with cool roof)	0.875
Cool roof cost	3.12 AUD/m^2 AUD: Australian dollar

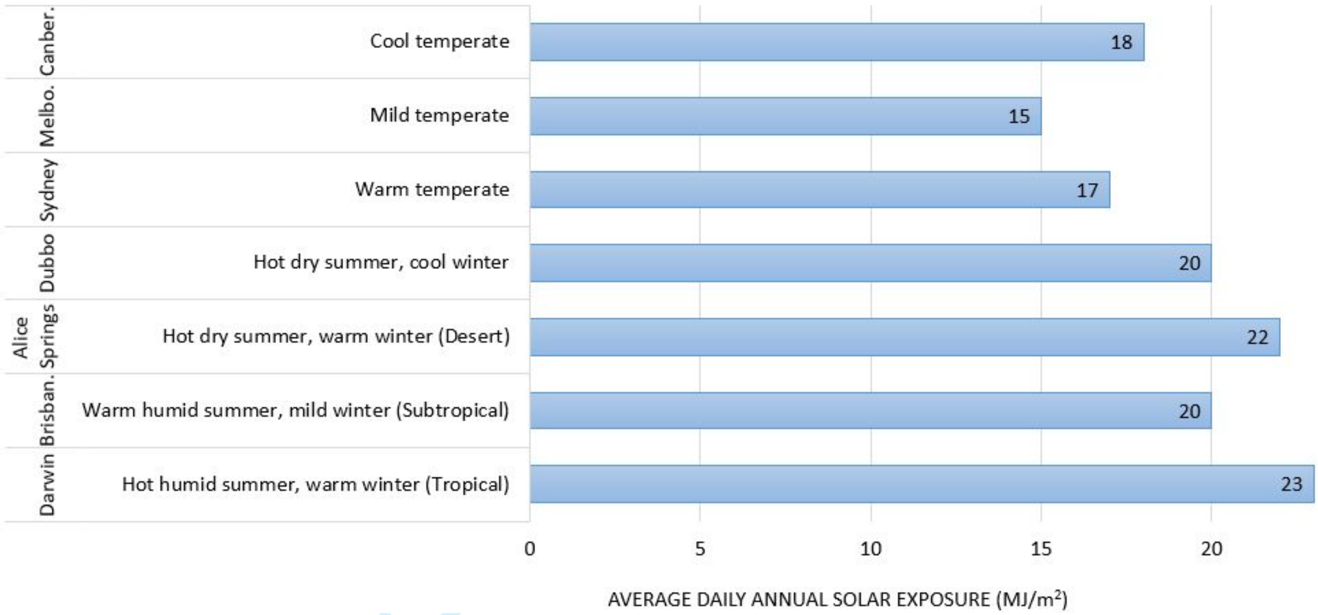


Fig. 5. Locations of Australian supermarkets with their types of climate and average annual daily solar exposure.

2.2. Supermarkets with cool roof technology in Canada

The two supermarkets analysed are situated in the Greater Toronto Area (GTA) and in Montreal. The Toronto supermarket is located in a single storey building in two construction vintages: pre-1980 and post 1980 with 750 m^2. The Toronto area has a continental humid climate with mild and humid summers and cool winters. The supermarket building has a gas and electric rooftop, constant volume packaged-single-zone HVAC system. Table II shows the technical characteristics of the supermarket roof in Toronto and Montreal (Akbari & Konopacki, 2004; Touchaei et al., 2016). The Montreal supermarket is located in a single storey building in two construction vintages: pre 1980 and post 1980 with an area of 2299 m^2. Montreal area has a continental humid climate with warm and humid summers and cool winters. Two HVAC installations have been analysed: a gas heating system and an electrical cooling system with the entry zone heated by an electric unit heater in the old construction and a furnace unit heater in the new construction. Fig. 6 shows the locations of the

Canadian supermarkets, their types of climate and the average annual daily solar exposure based on the solar resource map (2019) and the Government of Canada (2019) observation.

Table II. Technical characteristics of Toronto and Montreal supermarket roof.

Characteristics of the supermarket cool roof		
Supermarket city	**Toronto**	**Montreal**
Material	Plywood deck, over an unventilated and unconditioned plenum, above a studded ceiling frame	Plywood deck covered with gray mineral cap sheet
Pitched	Flat roof	Flat roof
Thermal insulation of the roof	fiberglass insulation	Multi-layer radiant barrier
Cool roof coating used	White elastomeric coating, White reflective skin.	White elastomeric coating, White reflective skin.
U-value (W/m^2K)	0.82	0.82
Solar reflectance (without cool roof)	0.2	0.2
Solar reflectance (with cool roof)	0.65	0.65
Cool roof cost	3.5 CAD/m^2 CAD: Canadian dollar	3.5 CAD/m^2

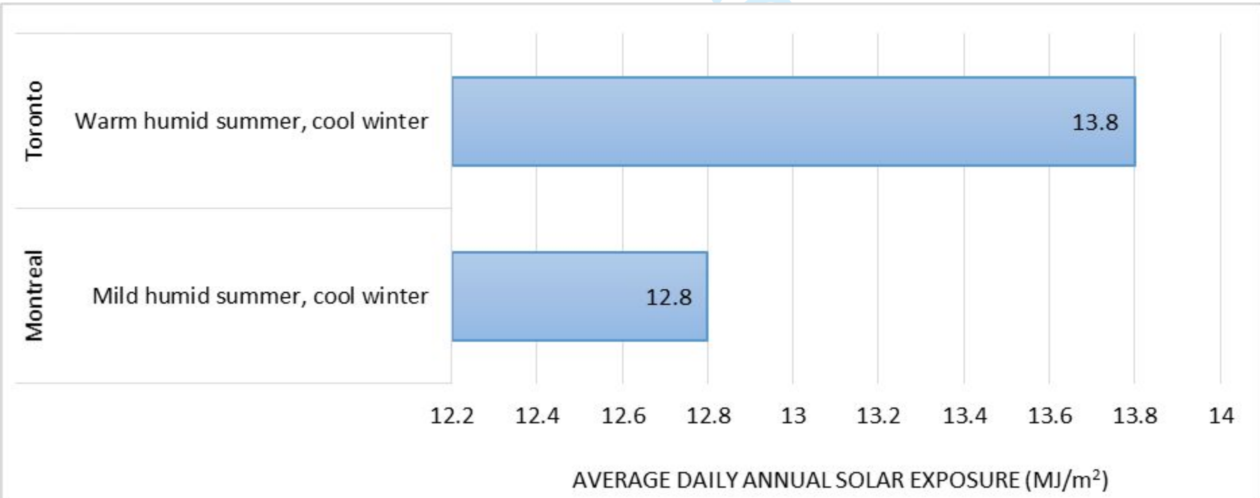


Fig. 6. Locations of Canadian supermarkets with their climate types and average annual daily solar exposure.

2.3. Supermarkets with cool roof technology in United States (U.S.)

The retail store analysed is located in Sacramento (California). The Sacramento supermarket is located in a single storey concrete tilt-up 1989 building with an area of 1600 m^2. Sacramento has a continental humid climate with mild and humid summers and cool winters. The supermarket building has roof top units for the HVAC system. Table III shows the technical characteristics of the supermarket roof in Sacramento (Akbari et al., 2005). Sacramento has very hot summers and warm humid winters with an average daily solar exposure annual of 22 MJ/m^2 suggested by The Map produced by the National Renewable Energy Laboratory for the U.S. Department of Energy (2019).

Table III. Technical characteristics of Sacramento (California) supermarket roof.

Characteristics of the supermarket cool roof	
Material	Plywood deck above a studded ceiling frame with fiberglass insulation, and with a sheet of drywall beneath
Pitched	Flat roof
Thermal insulation of the roof	Multi-layer radiant barrier (R-7 equivalent)
Cool roof coating used	Water based acrylic coating, White coating
U-value (W/m^2K)	0.82
Solar reflectance (without cool roof)	0.21
Solar reflectance (with cool roof)	0.80
Cool roof cost	2.4 USD/m^2 USD: United States dollar

2.4. Supermarkets with cool roof technology in Spain

The three supermarkets studied are located in important Spanish cities with different weather conditions: Madrid, Barcelona and Bilbao. On the one hand, the Madrid supermarket is a single storey building dated 1978 with an area of 1305 m^2. The city of Madrid has a transition climate between the cold semi-arid and the Mediterranean with cool winters and dry summers. On the other hand, the Barcelona supermarket is located in a single storey building dated 1987 with an area of 1275 m^2. The city of Barcelona has a Mediterranean climate with mild winters and dry warm summers. Finally, the Bilbao supermarket is a single storey building dated 1989 with an area of 950 m². The city of Bilbao has a mild oceanic climate with mild winters and warm summers. Table IV shows the technical characteristics of the supermarket roofs in Madrid, Barcelona and Bilbao. The HVAC systems had roof top units and used inverter technology being new equipments in all three cities. Fig. 7 shows the locations of the Spanish supermarkets, their types of climate and the average daily annual solar exposure by Spanish Government (Sancho et al., 2012).

Table IV. Technical characteristics of Madrid, Barcelona and Bilbao supermarket roof.

Characteristics of the supermarket cool roof			
Supermarket city	**Madrid**	**Barcelona**	**Bilbao**
Material	Metal	Metal	Sandwich panel. Metal structure and polyurethane (PUR)
Pitched	Flat roof (2%)	Flat roof (2.5%)	5%
Thermal insulation of the roof	Glass wool and kraft paper on one side has a steam barrier function.	Glass wool and kraft paper on one side has a steam barrier function.	Polyurethane (PUR)
Cool roof coating used	White elastomeric coating, White reflective skin.	White elastomeric coating, White reflective skin.	Water based acrylic coating. White reflective skin.
U-value (W/m^2K)	1.50	1.55	0.90
Solar reflectance (without cool roof)	0.2	0.2	0.2
Solar reflectance (with cool roof)	0.85	0.85	0.83
Cool roof cost	2.25 €/m² €: euro	2.25 €/m²	1.95 €/m²

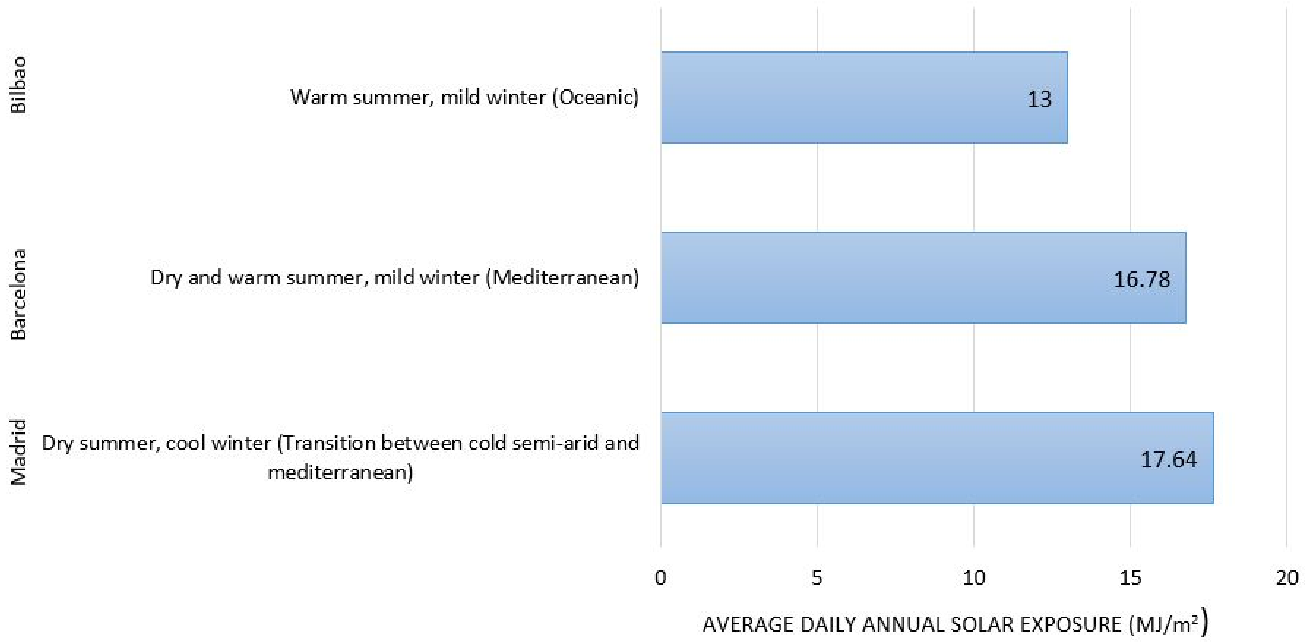


Fig. 7. Locations of Spanish supermarkets with their types of climate and average annual daily solar exposure.

3. Results

3.1. Australian supermarkets

Table V shows the data obtained in the case study supermarket analysis indicating the reduction of thermal loads and energy consumption associated with the use of the HVAC system, as well as the annual average energy reduction which makes the use of cool roof makes possible in the commercial establishment (Seifhashemi et al., 2018).

Table V. Results of cool roof coating on the case study Australian supermarket.

Indoor temperature reduction (ºC)	8-9
Cooling load reduction (W)	3.1
Cooling energy reduction (kWh/m² year)	3.9
Annual average energy reduction (kWh)	1628

As suggested by Seifhashemi et al. (2018), the data of annual HVAC energy use in the Australian supermarkets analysed as well as the energy savings per square meter and the percentage of energy saving and CO_2 emission reduction obtained with the use of cool roof technology are reflected in Table VI. It indicates that the percentage of energy savings obtained is greater in colder climates though the greater the energy savings per square meter is the hotter the climate.

Table VI. Annual HVAC energy use in Australian supermarkets, energy savings and CO_2 emission reduction obtained with the use of cool roof technology.

Supermarket	**Darwin**	**Brisbane**	**Alice Springs**	**Dubbo**	**Sydney**	**Melbourne**	**Canberra**
HVAC energy use (MWh/year)	47.83	19.78	22.82	12.86	10.69	5.62	6.95
HVAC energy use with cool roof (MWh/year)	44.38	17.12	19.42	10.92	8.78	4.48	4.93
Energy saving per m^2 ($kWh/year/m^2$)	3.43	2.65	3.38	1.94	1.91	1.14	2.00
Percentage of energy saving (%)	7.20	13.45	14.90	15.02	17.84	20.31	29.10
CO_2 emissions factor coefficient	0.78	0.93	0.78	0.99	0.99	1.34	0.99
Annual CO_2 emission reduction (t CO_2/year)	2.7	2.5	2.7	1.9	1.9	1.5	2.0
Annual CO_2 emission reduction per m^2 ($kgCO_2/year/m^2$)	2.7	2.5	2.7	1.9	1.9	1.5	2.0

The energy savings achieved with cool roof technology in energy consumption by the HVAC system translates into the reduction of CO_2 emissions. This level of emissions depends on the emission factors dependent on the type of electricity generation in the different areas of Australia. Based on the observation of the Commonwealth of Australia, Department of the Environment: the National Greenhouse Accounts Factor (2014) and the Department of Environment and Energy

(2018) Table V shows the CO_2 emission factor coefficients in the areas of the different supermarkets analysed and reflects the annual CO_2 emission reduction in the supermarkets analysed with the use of cool roof technology and per total supermarket surface (Seifhashemi et al., 2018). It indicates that the percentage of energy savings obtained is greater in colder climates but the hotter the climate the greater the energy saving per square meter of the supermarket. However, for the Brisbane supermarket the energy savings per square meter were lower than the Alice Springs one which has a cooler climate since Brisbane has a less annual average daily solar exposure than Alice Springs. Likewise, this occurs in the supermarket in Canberra.

3.2. Canadian supermarkets

The electrical consumption data of the HVAC system were analysed before and after the application of the cool roof on the supermarkets, allowing a comparison of the cooling loads 'before' and 'after' associated with the cool roof. Likewise, the energy reduction of the HVAC system in the supermarkets was calculated, obtaining an annual average percentage of energy savings. All this data is reflected in Table VII based on the publication by Akbari & Konopacki (2004) and Touchaei et al. (2016). The savings achieved with cool roof technology in energy consumption by the HVAC system translates into the reduction of CO_2 emissions. This level of emissions depends on the emission factors dependent on the type of electricity generation in the different areas of Canada. The following step was implemented (refer Table VI) using the electricityMap (2019) and the TAF's GHG Quantification Methodology-City of Toronto (2016), which shows the CO_2 emissions factors coefficient in the areas of the different supermarkets analysed and reflects the data of annual CO_2 emission reduction in the Canadian supermarkets analysed with the use of cool roof technology (Akbari & Konopacki, 2004; Touchaei et al., 2016). As in the Australian study, it indicates that the percentage of energy savings obtained is greater in colder climates. Additionally, this analysis

270 showed the older the building is the greater the energy savings are (it has a poorer previous thermal
271 insulation).
272
273 **Table VII.** Annual HVAC energy use in Canadian supermarkets, energy savings and CO_2 emission
274 reduction obtained with the use of cool roof technology.

Supermarket	Toronto (pre 1980)	Toronto (post 1980)	Montreal (pre 1980)	Montreal (post 1980)
Cooling energy use (MWh/year)	151.70	62.25	141.37	96.17
Heating energy use (GJ/year)	233.25	75.75	2184.05	735.68
Cooling energy saving (GJ/year)	7.13	2.27	36.5	15.01
Heating energy saving (GJ/year)	-3.75	-4.50	-114.95	-22.99
Percentage of energy saving (%)	4.6	3.5	19.7	13.6
CO_2 emission factors coefficient with Natural Gas ($kgCO_2eq/m^3$)	1.90	1.90	1.90	1.90
CO_2 emission factors coefficient with Electricity ($kgCO_2eq/kWh$)	0.23	0.23	0.23	0.23
Annual CO_2 emission reduction (t CO_2/year)	1.63	0.51	5.49	2.33
Annual CO_2 emission reduction per m^2 (kg CO_2/year/m^2)	2.17	0.68	2.39	1.01

275

276 **3.3. U.S. supermarket**

277 To detect out the reduction of the energy consumption in the supermarket in California achieved by
278 the decrease of the energy associated with the HVAC system, the annual consumptions needed to
279 air-condition the supermarket before and after applying the cool roof technology were measured.
280 Based on the publication by Akbari et al. (2005), Table VIII reflects the data of annual HVAC

energy use, HVAC energy savings and the percentage of energy saving in the U.S. by using cool roof technology. The savings achieved with cool roof technology in energy consumption by the HVAC system is translated into the reduction of CO_2 emissions. These levels of emissions depend on the emission factors dependent on the type of electricity generation in different areas of U.S. According to the results obtained from the ElectricityMap (2019) and Energy Information Administration (EIA) (2019), Table VIII shows the CO_2 emissions factors coefficient in the area of the supermarket analysed and reflects the data of annual CO_2 emission reduction in the U.S. supermarket analysed with the use of cool roof technology (Akbari et al., 2005).

Table VIII. Annual HVAC energy use in the U.S. supermarket, energy savings and CO_2 emission reduction obtained with the use of cool roof technology.

Supermarket	**Sacramento (California)**
HVAC energy use (MWh/year)	48.60
HVAC energy saving (MWh/year)	18.40
Percentage of energy saving (%)	37.9
CO_2 emission factors coefficient with Electricity ($kgCO_2eq/kWh$)	0.16
Annual CO_2 emission reduction (t CO_2/year)	3.94
Annual CO_2 emission reduction per m^2 (kg $CO_2/year/m^2$)	2.46

3.4. Spanish supermarkets

The data of annual HVAC energy use in the Spanish supermarkets analysed as well as the energy savings per square meter, the percentage of energy saving and CO_2 emission reduction obtained with the use of cool roof technology are reflected in Table IX. It indicates that the percentage of energy savings with extreme climates, hot summers, cool winters and in older buildings was higher in Madrid. Moreover, the supermarket in the north of Spain (Bilbao), with mild summers and winters carried out less energy savings per square meter than the Mediterranean supermarket with warmer summers and winters.

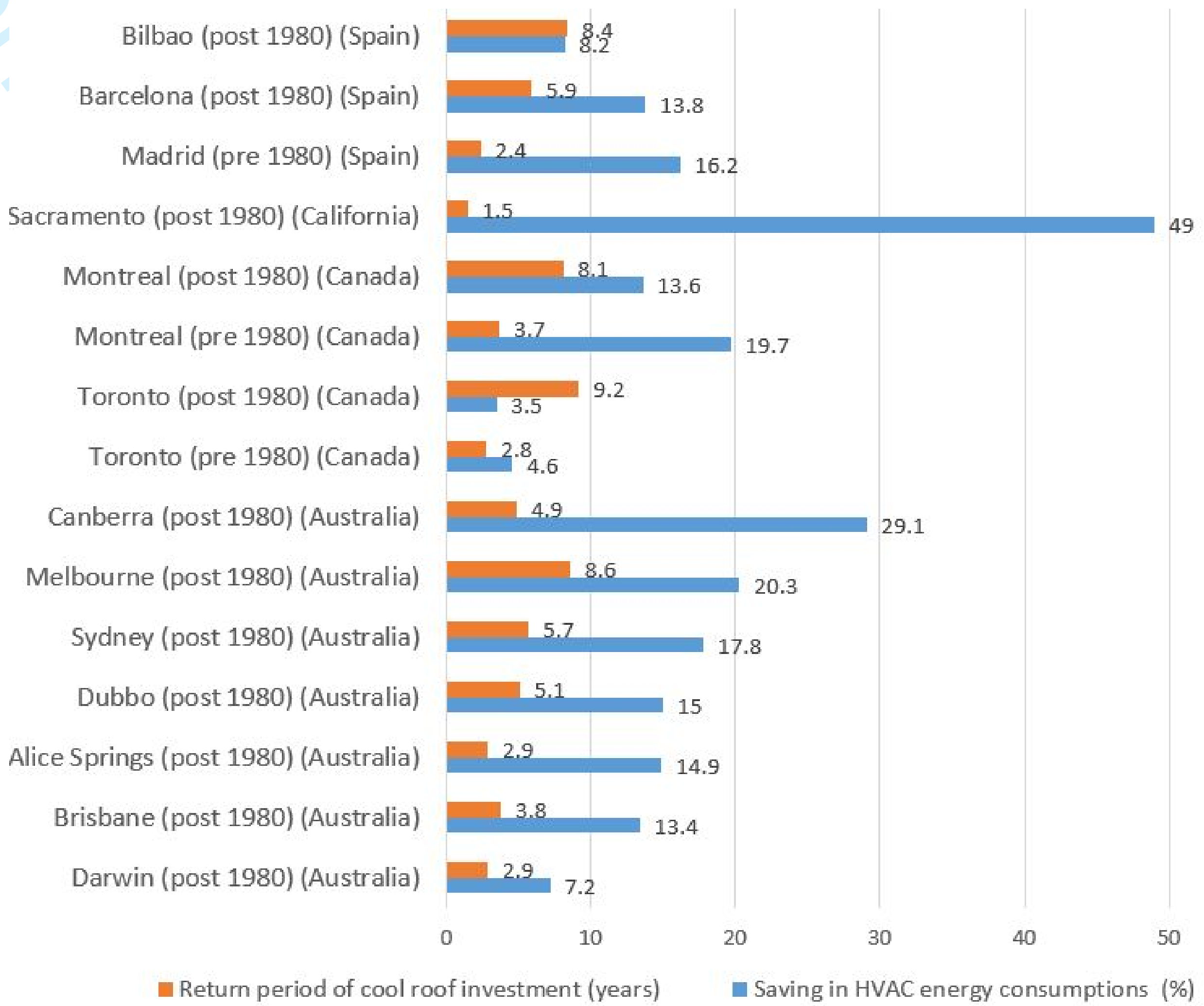
Table IX. Annual HVAC energy use in Spanish supermarkets, energy savings and CO_2 emission reduction obtained with the use of cool roof technology.

Supermarket	**Madrid (pre 1980)**	**Barcelona (post 1980)**	**Bilbao (post 1980)**
Cooling energy use (MWh/year)	23.62	16.97	10.32
Heating energy use (MWh/year)	27.89	10.30	10.47
Cooling energy saving (MWh/year)	10.66	4.39	2.31
Heating energy saving (MWh/year)	-1.39	-0.63	-0.61
Percentage of energy saving (%)	16.2	13.8	8.2
CO_2 emission factors coefficient with Electricity ($kgCO_2eq/kWh$)	0.38	0.38	0.38
Annual CO_2 emission reduction ($t\ CO_2/year$)	3.52	1.43	0.65
Annual CO_2 emission reduction per m^2 ($kg\ CO_2/year/m^2$)	2.70	1.12	0.68

The GHG emissions factor used was the energy mix of 2018, according to official values issued by the National Energy Commission of Spain, which was 0.38 $kgCO_2/kWh$ for the main electricity trading company in Spain (Ministerio para la Transición Ecológica 2019) when the price of electricity at the time of this analysis of 0.13 €/kWh.

4. Discussion

In this study, we focused on several supermarkets located in different parts of the world with different weather conditions and different times of construction. The percentage of energy saving obtained with the analysed cool roof technology are detailed in Table VI, Table VII, Table VIII and Table IX. Three factors contribute to the high savings in supermarkets: large surface roof, low roof insulation and long hours of HVAC system operation. Monitoring energy use in occupied buildings is always subject to statistical variation due to the occupancy behaviour and the associated thermal loads. The analysis of the energy consumption data of the HVAC systems was direct and precise since the operation of the equipment has remained uniform both before and after the application of the cool roof technology. In addition, cool roofs get greater dimensional stability of the cover stratigraphy and the underlying load-bearing structures due to the reduced influence of summer temperatures (minor movements, dilations, cracks, and others). Furthermore, a greater durability and life expectancy of waterproof cover surfaces since the action of natural aging induced by heat is greatly reduced by the low surface temperature is obtained.


Bilbao (post 1980) (Spain)
Barcelona (post 1980) (Spain)
Madrid (pre 1980) (Spain)
Sacramento (post 1980) (California)
Montreal (post 1980) (Canada)
Montreal (pre 1980) (Canada)
Toronto (post 1980) (Canada)
Toronto (pre 1980) (Canada)
Canberra (post 1980) (Australia)
Melbourne (post 1980) (Australia)
Sydney (post 1980) (Australia)
Dubbo (post 1980) (Australia)
Alice Springs (post 1980) (Australia)
Brisbane (post 1980) (Australia)
Darwin (post 1980) (Australia)
8.4
8.2
5.9
13.8
2.4
16.2
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49
8.1
13.6
3.7
19.7
9.2
3.5
2.8
4.6
4.9
29.1
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50
Return period of cool roof investment (years)
Saving in HVAC energy consumptions (%)

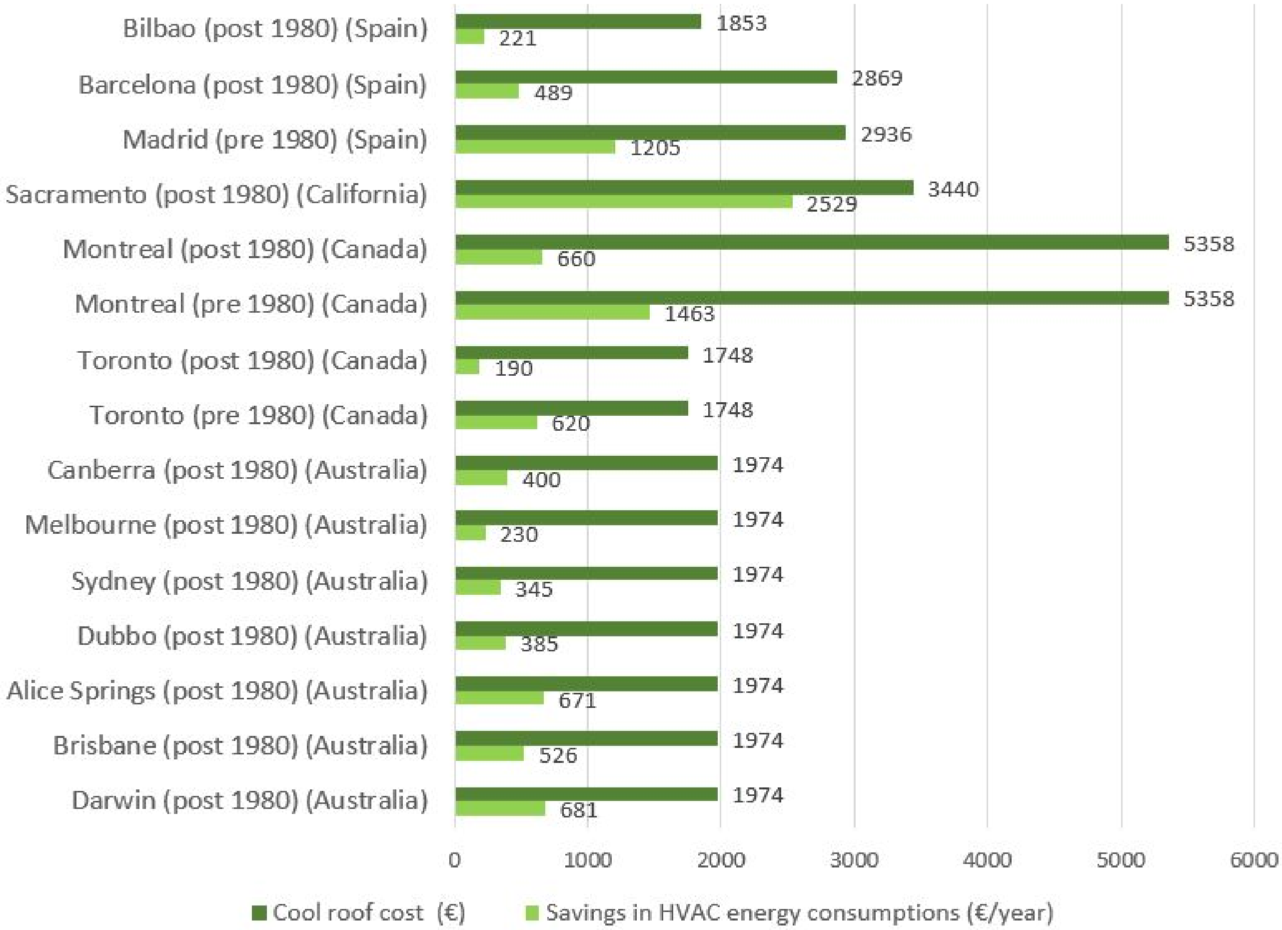

Fig. 8. Savings in the HVAC energy consumption obtained with cool roof technology, cost and return period of cool roof investment in the analysed supermarkets.

Energy savings translate into significant savings of CO_2 emissions, these savings are detailed in Table VI, Table VII, Table VIII and Table IX. Fig. 8 shows the economic savings achieved with the application of cool roof technology in the different supermarkets analysed according to the energy tariffs of the different countries, the return period of the investment has also been calculated. Cool roof technology requires an initial cost, including material and application labour but their maintenance costs are similar as traditional roof covers. Additionally, cool roof cleaning costs have been included to maintain the roof's optimal properties. An average degradation factor, provided by the manufacturer, has also been taken into account when assessing the application of the technology. The return times of the investment are not high and the probable increase in the energy price will cause a decrease. In the present scenario, where legal constraints force the reduction of GHG emissions, it certainly improves the prospect meaning that technology is advisable. Cool roofs can potentially cool the city by several degrees, lowered urban air temperatures can further reduce cooling-energy demand (Akbari & Konopacki, 2004) and cooler ambient conditions can slow the rate of smog (O_3) formation which can have a significant effect on ambient air quality. The roof of a building constitutes the most exposed envelope and is decisive in the thermal exchange with the external environment. The cool roof system requires an annual maintenance consisting of cleaning the surface to prevent the cover from darkening with the dirt deposited over time, in the rainiest areas this cleaning will be less necessary. It must be replaced so as to maintain full capacity every 15 years, which is a lower period than the recovery time of the investment.

5. Conclusions

With the study of the exposed cases, the following conclusions have been obtained on the use of cool roofs technology in supermarkets:

The payback period in cool roof technology vary between 1.5 and 9 years and depend both on the supermarket climate zone and the age of the building. The increase in the price of energy and the reduction of the cost of cool roof technology due to the increase in its use. Additionally, the possible financial aid provided by the public administrations to promote the use of technologies that improve energy efficiency in buildings smooth the way for the implementation of cool roof technology. The savings in HVAC electricity consumption vary between 3.5% and 38%. The expected savings are higher in very hot, sunny and cloudless climates involving all climate zones studied. However, the savings are higher in the oldest buildings with old thermal roof insulation and in supermarkets with a cooler surface.

The cooling savings are dominant compared to the heating savings of the HVAC system, reaching up to 8 kWh/year*m^2.

The colder the climate and the older the supermarket with an inferior thermal insulation is the greater the percentage of energy savings are.

The hotter the climate is and the more annual average daily solar exposure the supermarket has the greater the energy savings per square meter are.

The economic savings are strongly influenced by the price of energy in different parts of the world and by the foreseeable increases in the future. Thus, the higher the cost of energy the more interesting the application of cool roofs are.

The use of cool roofs decreases non-industrial GHG emissions with an annual reduction of CO_2 emissions between 0.7-2.7 $kgCO_2/m^2$. The implementation is significant in order to reduce pollutant emissions to the levels that the states have committed to achieving in international environmental agreements.

The use of this technology decreases internal temperatures and improves the energy efficiency by reducing energy consumption while increasing the comfort levels of the supermarket, both in the air-conditioned and non-air-conditioned areas.

Moreover, an indirect benefit for the reduction in ambient temperature reduction also called urban heat island effect is obtained. The use of cool roofs can be decisive in reducing this effect.

It satisfies, with regulatory requirements set in the norms of building to improve the energy efficiency in new constructions.

Increasing environmental awareness by companies, in addition to a competitive advantage due to the economic savings achieved with the implementation of measures to increase energy efficiency, will encourage customers to perceive a higher quality of service.

It is only used in a residual way presenting a great capacity for growth particularly in the warmest areas with the highest solar radiation. Energy-based IS can present a high level of implementation and future upgrowth, expediting the development of a circular economy with low energy consumption.

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Characteristics of the supermarket cool roof	
Material	Metal
Pitched	Low pitched (3.5%)
Thermal insulation of the roof	Reflective foil-backed bulk insulation blanket under roof sheeting
Cool roof coating used	Water based acrylic coating, specifically Shield coats Thermobond HRC (Artic White)
U-value (Thermal transmittance)	1.97 (W/m^2K)
Solar reflectance (without cool roof)	0.2
Solar reflectance (with cool roof)	0.875
Cool roof cost	3.12 AUD/m^2 AUD: Australian dollar

Characteristics of the supermarket cool roof		
Supermarket city	**Toronto**	**Montreal**
Material	Plywood deck, over an unventilated and unconditioned plenum, above a studded ceiling frame	Plywood deck covered with gray mineral cap sheet
Pitched	Flat roof	Flat roof
Thermal insulation of the roof	fiberglass insulation	Multi-layer radiant barrier
Cool roof coating used	White elastomeric coating, White reflective skin.	White elastomeric coating, White reflective skin.
U-value (W/m^{2}K)	0.82	0.82
Solar reflectance (without cool roof)	0.2	0.2
Solar reflectance (with cool roof)	0.65	0.65
Cool roof cost	3.5 CAD/m^2 CAD: Canadian dollar	3.5 CAD/m^2

Characteristics of the supermarket cool roof	
Material	Plywood deck above a studded ceiling frame with fiberglass insulation, and with a sheet of drywall beneath
Pitched	Flat roof
Thermal insulation of the roof	Multi-layer radiant barrier (R-7 equivalent)
Cool roof coating used	Water based acrylic coating, White coating
U-value (W/m^2K)	0.82
Solar reflectance (without cool roof)	0.21
Solar reflectance (with cool roof)	0.80
Cool roof cost	2.4 USD/m^2 USD: United States dollar

Characteristics of the supermarket cool roof			
Supermarket city	**Madrid**	**Barcelona**	**Bilbao**
Material	Metal	Metal	Sandwich panel. Metal structure and polyurethane (PUR)
Pitched	Flat roof (2%)	Flat roof (2.5%)	5%
Thermal insulation of the roof	Glass wool and kraft paper on one side has a steam barrier function.	Glass wool and kraft paper on one side has a steam barrier function.	Polyurethane (PUR)
Cool roof coating used	White elastomeric coating, White reflective skin.	White elastomeric coating, White reflective skin.	Water based acrylic coating. White reflective skin.
U-value (W/m^2K)	1.50	1.55	0.90
Solar reflectance (without cool roof)	0.2	0.2	0.2
Solar reflectance (with cool roof)	0.85	0.85	0.83
Cool roof cost	2.25 €/m^2 €: euro	2.25 €/m^2	1.95 €/m^2

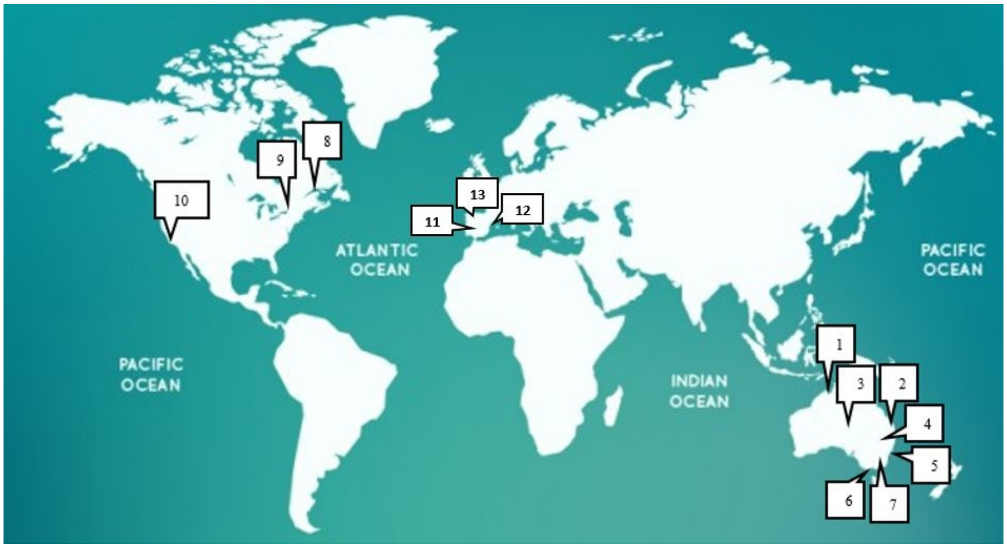
Indoor temperature reduction (ºC)	8-9
Cooling load reduction (W)	3.1
Cooling energy reduction (kWh/m^2 year)	3.9
Annual average energy reduction (kWh)	1628

Supermarket	Darwin	Brisbane	Alice Springs	Dubbo	Sydney	Melbourne	Canberra
HVAC energy use (MWh/year)	47.83	19.78	22.82	12.86	10.69	5.62	6.95
HVAC energy use with cool roof (MWh/year)	44.38	17.12	19.42	10.92	8.78	4.48	4.93
Energy saving per m^2 (kWh/year/m^2)	3.43	2.65	3.38	1.94	1.91	1.14	2.00
Percentage of energy saving (%)	7.20	13.45	14.90	15.02	17.84	20.31	29.10
CO_2 emissions factor coefficient	0.78	0.93	0.78	0.99	0.99	1.34	0.99
Annual CO_2 emission reduction (t CO_2/year)	2.7	2.5	2.7	1.9	1.9	1.5	2.0
Annual CO_2 emission reduction per m^2 (kgCO_2/year/m^2)	2.7	2.5	2.7	1.9	1.9	1.5	2.0

Supermarket	Toronto (pre 1980)	Toronto (post 1980)	Montreal (pre 1980)	Montreal (post 1980)
Cooling energy use (MWh/year)	151.70	62.25	141.37	96.17
Heating energy use (GJ/year)	233.25	75.75	2184.05	735.68
Cooling energy saving (GJ/year)	7.13	2.27	36.5	15.01
Heating energy saving (GJ/year)	-3.75	-4.50	-114.95	-22.99
Percentage of energy saving (%)	4.6	3.5	19.7	13.6
CO_2 emission factors coefficient with Natural Gas ($kgCO_2eq/m^3$)	1.90	1.90	1.90	1.90
CO_2 emission factors coefficient with Electricity ($kgCO_2eq/kWh$)	0.23	0.23	0.23	0.23
Annual CO_2 emission reduction (t CO_2/year)	1.63	0.51	5.49	2.33
Annual CO_2 emission reduction per m^2 (kg CO_2/year/m^2)	2.17	0.68	2.39	1.01

Supermarket	**Sacramento (California)**
HVAC energy use (MWh/year)	48.60
HVAC energy saving (MWh/year)	18.40
Percentage of energy saving (%)	37.9
CO_2 emission factors coefficient with Electricity ($kgCO_2eq/kWh$)	0.16
Annual CO_2 emission reduction (t CO_2/year)	3.94
Annual CO_2 emission reduction per m^2 (kg CO_2/year/m^2)	2.46

Supermarket	Madrid (pre 1980)	Barcelona (post 1980)	Bilbao (post 1980)
Cooling energy use (MWh/year)	23.62	16.97	10.32
Heating energy use (MWh/year)	27.89	10.30	10.47
Cooling energy saving (MWh/year)	10.66	4.39	2.31
Heating energy saving (MWh/year)	-1.39	-0.63	-0.61
Percentage of energy saving (%)	16.2	13.8	8.2
CO_2 emission factors coefficient with Electricity ($kgCO_2eq/kWh$)	0.38	0.38	0.38
Annual CO_2 emission reduction ($t\ CO_2$/year)	3.52	1.43	0.65
Annual CO_2 emission reduction per m^2 ($kg\ CO_2/year/m^2$)	2.70	1.12	0.68



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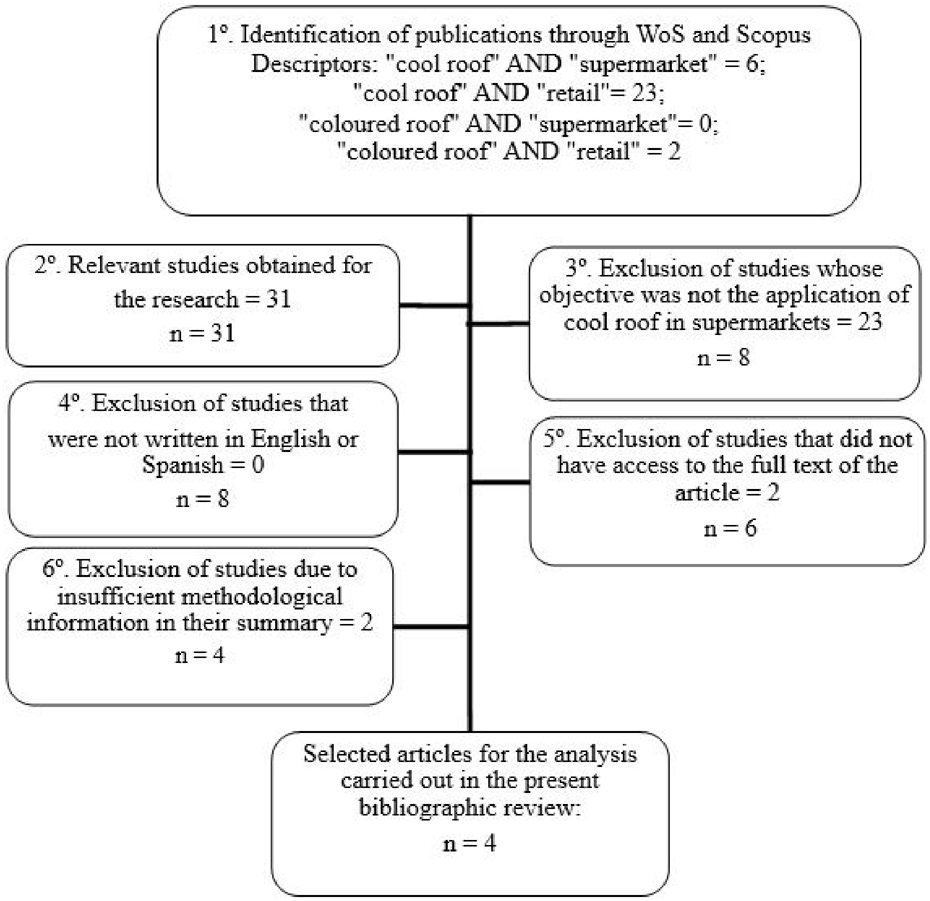

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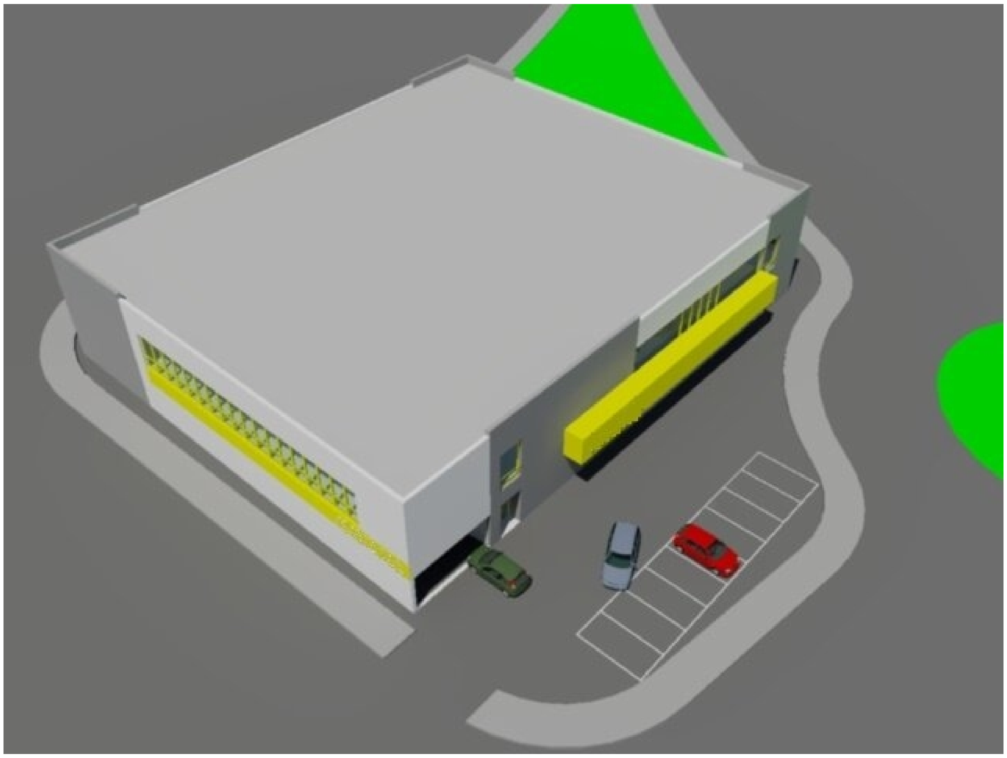

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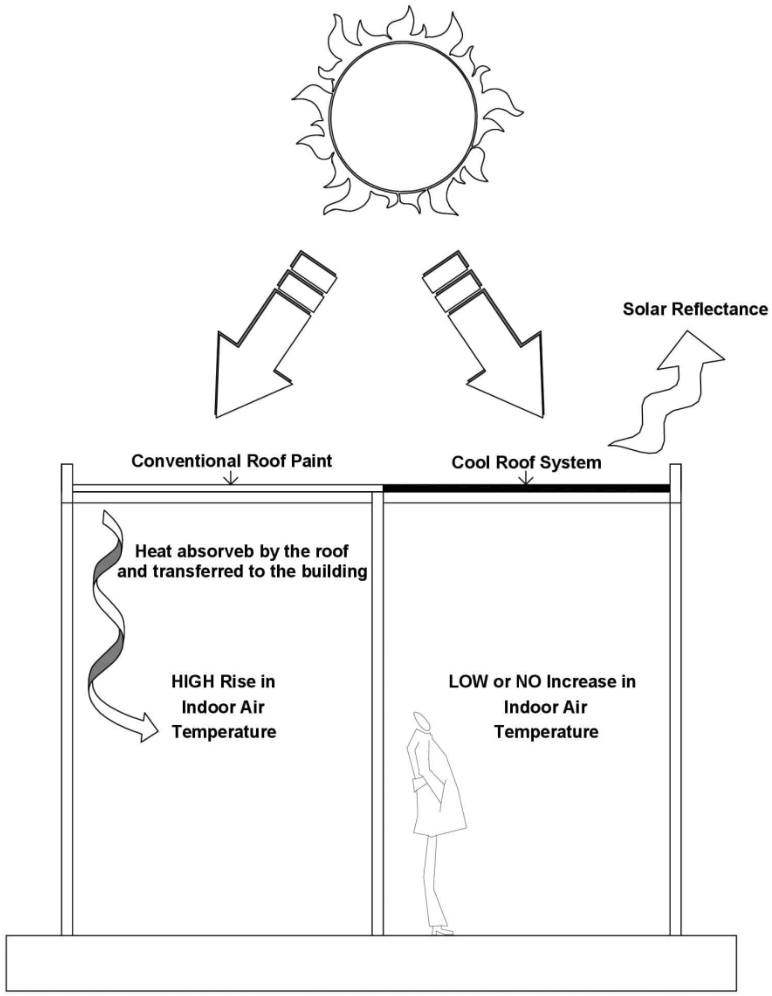

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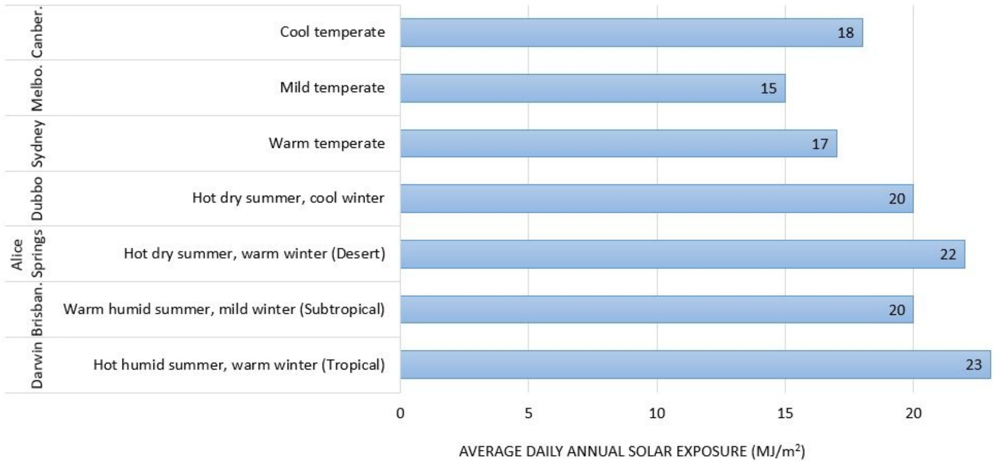

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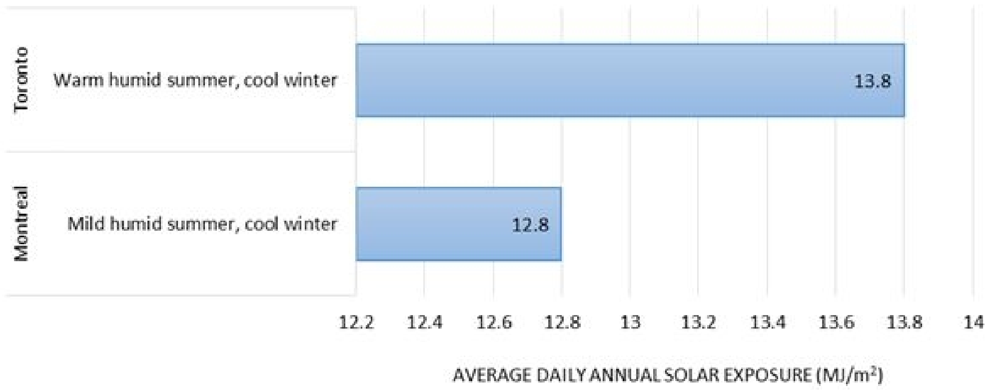

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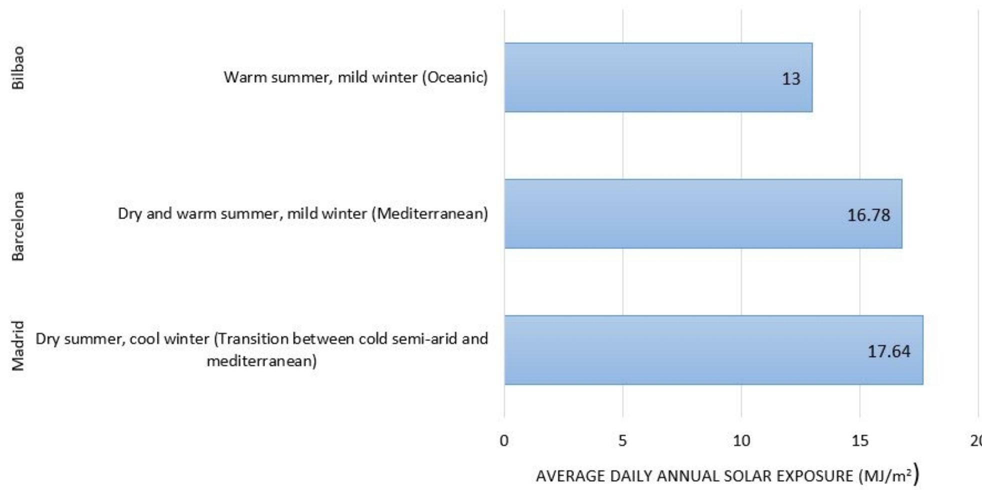

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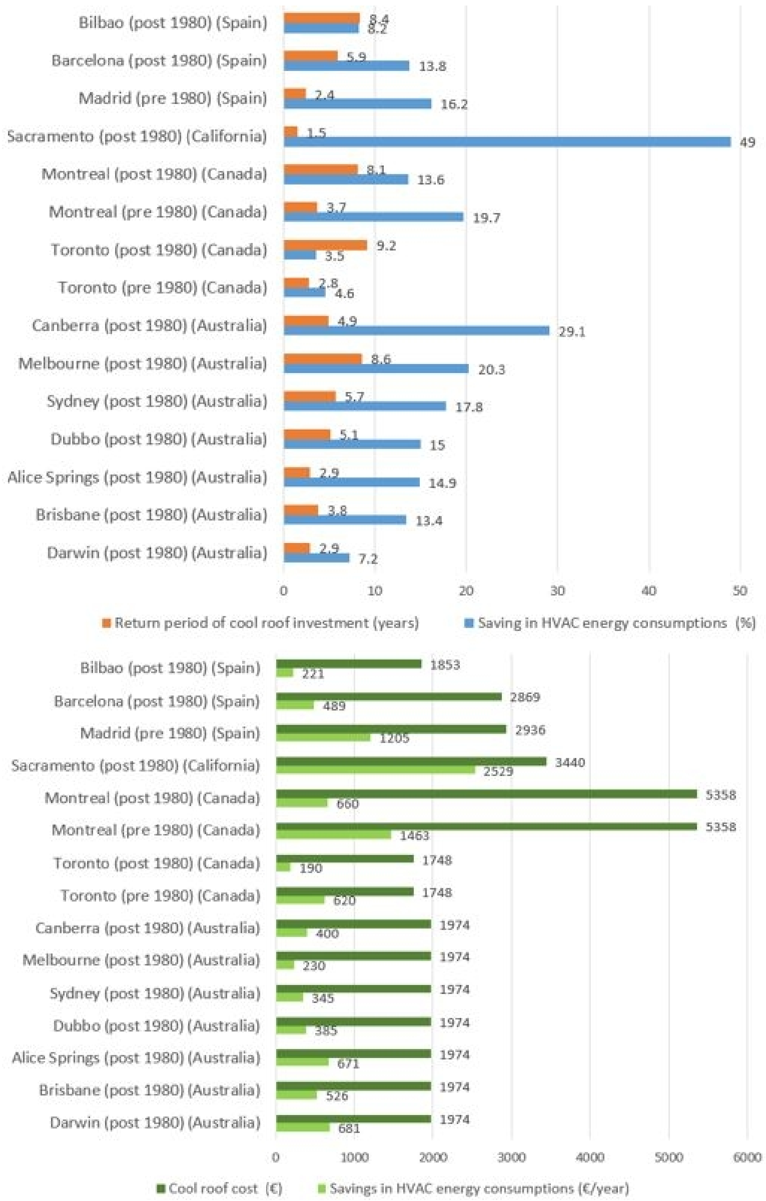

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