LCM of green food production in Mediterranean cities: environmental benefits associated to the energy savings in the use stage of Roof Top Greenhouse (RTG) systems. A case study in Barcelona (Catalonia, Spain).

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Abstract. The current food model is produced and processed through a linear urban metabolism. One way possible for reducing the carbon footprint of cities is integrating agriculture production in them, through urban agriculture systems in buildings, such as roof top greenhouses (RTG). This study assesses the energy and GHG emissions savings of RTG systems in Mediterranean cities in relation to the current constructions, through a pilot study situated in a catering service building in the city of Barcelona (Spain). The study focuses on the thermal behavior of roof and its effects on the demand for cooling and heating. Once the different structural systems and materials of the building and greenhouse were defined, five evaluation scenarios were modelled in the "Design Builder" energy simulation program. Preliminary results show that the RTG system requires interconnection with the building to derive greater benefits of energy efficiency.

1 Introduction

Cities in spite of generating knowledge and welfare of its inhabitants, directly and indirectly generate enormous pressure on the natural environment destroying ecosystems, green areas, biodiversity and consuming resources. Despite representing only 2.7% of the world surface area [1], the world´s cities are responsible for 75% of the world´s energy consumption and 80% of greenhouse gas emissions [2]. Cities provide an extensive range of services that require large amounts of energy and matter.

Internationally, the current energy model and its negative impact on the environment has led governments of the states and cities to consider various measures, through agreements such as the Rio de Janeiro Summit, Aalborg, Kyoto and Johannesburg [3].

1.1 Energy in buildings

The architecture occupies and transforms the environment in which it sits. It takes the form of construction which, like other industries, is based on the production model of the industrial revolution, defined by the linear sequence: mining, manufacturing and residue [4]. According to the IPCC buildings provide the most economic mitigation potential for reduction of CO_2 emissions [5].

Energy efficiency is a factor of great importance as a tool for sustainable buildings. Energy saving is without doubt the fastest, most efficient and most profitable way reduce emissions and improve air quality, so it is necessary to promote the implementation of new policies and new technologies [6].

Buildings have been detected as a priority area in reducing the total energy consumption within the European Union, since 40% of the total consumption corresponds to this sector [7].

In the Mediterranean environment the building standards have an important role. In the case of Spain, the Building Technical Code (CTE), with particular reference to the closure of buildings and that their involvement is crucial in saving energy through insulation, thermal inertia, exposure to radiation [8].

The heating and air conditioning are the main consumers of energy, and make up two thirds of total energy consumption of a building. However, most of this energy is wasted due to lack of insulation. Applying energy efficiency techniques can reduce demand by 70-90% energy for heating and air conditioning [9].

1.1 Green and food strategies

Green spaces play a significant role in urban environments contributing to public health and increasing the quality of life of urban citizens [10].
Food production in western cities is starting to become a feasible option of self-sufficiency. The current food model is produced and processed through a linear urban metabolism [11]. In contrast with this lineal system existing a productive model from the ecological industry with closed cycles, based on the example of the biosphere as a recycling machine [12].

In the Mediterranean region, various projects in new neighbourhoods and rehabilitation projects in existing neighbourhoods have incorporated food production and flow synergy techniques. Farreny et al. (2009) carried out an interdisciplinary study of concepts for a sustainable district in Barcelona, Spain, considering the incorporation of agriculture into the urban structure [13].
In Latin American cities (Merida, Mexico) has quantified the reduction of carbon footprint associated with the use of social housing with the integration of food-growing areas. The results showed 18% of reduction [14].

Currently, actions to promote the introduction of green or agricultural spaces into buildings are being implemented by means of different strategies.
Green roofs (GR), vertical farms (VF) and roof top greenhouses (RTG) are the three main proposals for integration in buildings. These systems not only approximate the horticultural products to consumer but also increase the thermal insulation of the building.

VF is an innovative proposal consisting of skyscrapers built exclusively for food production. One barrier regarding the implementation of VF is the large investment made in constructing and integrating technologies [15].

GR also contribute to naturalize cities can create an insulating effect and CO_2 sink. According to a recent study by researchers from Michigan (USA), carbon fixation in green roofs with sedum plants is 375 g CO_2/m^2 [16]. Another of green roofs in

buildings accounts for 2% savings in electricity consumption and 11% in heating through computer energy simulation models [17].
In the city of Barcelona, Spain, the City Council, in the framework of its Agenda 21, is carrying out studies to implement green rooftops and plant walls as a strategy to increase the green spaces within the urban area of this compact city. Preliminary results of this study indicated in 2607 hectares of roof surface can be transformed into green roofs. 67% of the surface corresponding to flat roofs [18].

RTG refers to the intensive production greenhouses built on rooftops without any type of interconnection. In North America have implemented this type of system. Some examples can be found in New York City where a number of environmental education centres with rooftop facilities for food production have been built [19].

Until now, RTG has been developed for educational and marketing purposes and therefore energy savings for the building haven´t still being quantified.

2 Goal and objectives

This study assesses the energy and GHG emissions savings of RTG systems in Mediterranean cities in relation to the current constructions, through a pilot study situated in a catering service building in the city of Barcelona (Spain).
The study focuses on the thermal behavior of roof and its effects on the demand for cooling and heating (Fig 1). It integrates architectural tools and life cycle assessment.

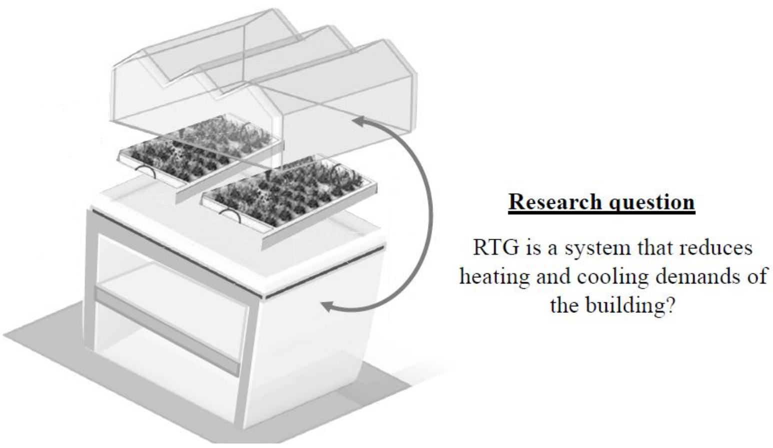

Fig.1: System study: RTG (Building / Greenhouse)

3 Materials and methods

3.1 Case study area: catering service building (Barcelona, Spain)

Barcelona is located on the north-eastern coast of Catalonia, Spain. Is a dense and compact Mediterranean city with a population of approximately 1.6 million inhabitants. The city lies at a longitude of 2.1ºE and latitude of 41.3ºN. Has an average rainfall of 550mm and an average annual temperature of 15.5ºC. The psychrometric chart for Barcelona shows a greater requirement for heating than cooling (35,123 heating degree hours versus 9,195 cooling degree hours) indicating a need for passive strategies to increase heat gain indoor of buildings [20].

The case study is a catering service building in the Horta-Guinardó district. It consists of a single plant and has an area of flat roof of 290.6 m^2 (Fig. 2). This building is listed within the potential buildings for green roofs in the technical report on the implementation of roofs and green walls in the city of Barcelona [21].

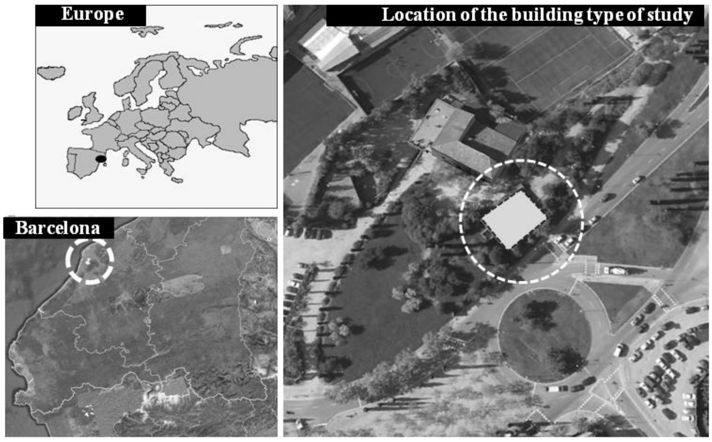

Fig. 2: Location of study area.

3.2 Study phases

Figure 3 summarizes the different phases of the study: definition of scenarios, tools and analysis of results.

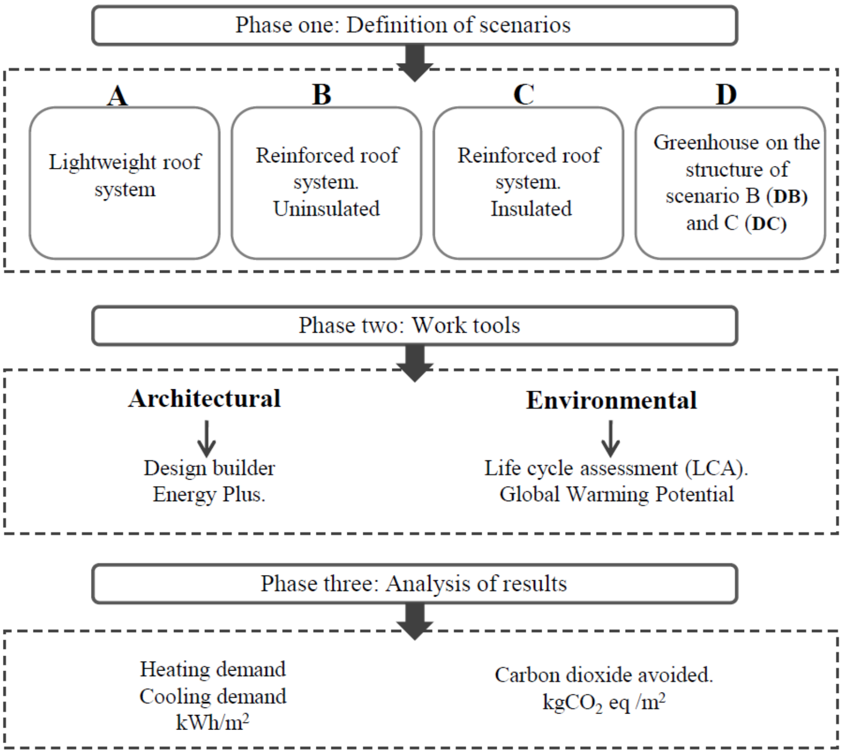

Fig.3: Phases of study: definition of scenarios, work tools and analysis

3.2.1 Phase one: Definition of scenarios

We conducted a comparative study on three construction alternatives on the roof of the building selected to correspond to frequently used settings in the service buildings of Barcelona. We defined four scenarios:
(A) Lightweight roof system (B) Reinforced roof system (Uninsulated) (C) Reinforced roof system (Insulated), and (D) RTG as an alternative structural system.

The greenhouse prototype is the Mediterranean one that consists of a relatively light structure adapted to the mild climatic conditions of the Mediterranean. It is designed to withstand the wind more than the snow. It is usually a plastic film rooftop and has a large surface area of windows to eliminate excess heat [22]. In some cases it has a heating system, although in the Southern Mediterranean heating is not usually essential. It is a predominantly passive greenhouse, meaning that it has low energy consumption and little air conditioning equipment, since the Mediterranean climate is by nature very favourable for growing crops [23].

Table 1 presents a summary of the specifications of the materials used in each of the scenarios.

Tab.1: Material considered in the study scenarios

Scenario	Materials
A	Plasterboard, air gap, asphalt
B	Plasterboard, cast concrete, asphalt
C	Plasterboard, cast concrete, EPS expanded polystyrene, asphalt
D	Green roof. Low density PE (greenhouse)

3.2.2 Phase two: Architectural and environmental tools

Architectural tools: The scenarios were modelled in the "DesignBuilder" energy simulation program, which uses the EnergyPlus dynamic simulation process to generate performance data, from climate and thermal characteristics of the materials data. The program allows the calculation of heating and cooling loads by the method adopted by ASHRAE and implemented in Energy Plus [24]. Climate files of Barcelona, Spain in Energy Plus Weather (EPW) format were used for simulations [25].

The main parameters for the simulation were: Comfortable temperature in winter of 21º C and in summer 26 º C. Occupation of 0.20 persons/m^2, internal loads of 20 W/m^2 and illumination of 5 W/m^2. It was considered a 16 hour daily operation of the restaurant.

The greenhouse was considered as an empty space with no environmental conditioning systems (heating / cooling) only natural ventilation. Ventilation is performed through windows located on the deck scheduled to open when the temperature of the greenhouse was greater than optimal for proper operation.

Environmental tools: Environmental assessment was carried out by using Life cycle assessment (LCA) methodology and according the ISO 14040 standard [26]. In this paper, we are only going to focus on global warming potential (GWP) impact category that measure the emissions of carbon dioxide generated by product, process or activity by accounting and evaluating the resources' consumption and emissions. In this case we will focus on carbon dioxide emissions associated to the energy use to maintain the comfort conditions in the building on the four scenarios only in use stage. Ecoinvent for Electricity production mix in Spain was used for the GWP associated with each scenario. The results are presented in $kgCO_2$ eq [27].

3.2.3 Phase three: Analysis of results

The heating and cooling demands are normalized kWh/m^2 in summer (April 1 to September 30), winter (October 1 to march 31) and the annual total. Is presented in percentage energy savings at each scenario. The results of the annual emissions are presented in $kgCO_2$ eq/m^2.

4 Results

Demands results obtained of the use stage with the Design Builder tool for each of the scenarios are presented in Table 2.

Tab.2: Cooling and heating demand in summer and winter (kWh/m^2)

Scenario	Summer		% savings	Winter		% savings
	C	H		C	H	
A	118.31	7.87	Current	3.88	80.39	Current
B	80.40	7.03	31	0.85	82.51	1.07
C	55.06	4.28	53	0.30	59.66	29
D (B)	67.89	7.32	40	0.58	86.10	0
D (C)	69.38	7.13	39	0.63	84.26	0

C: Cooling H: Heating

The results show that the scenario C reduces the summer cooling demand by 53% compared to scenario A and 32% compared with scenario B, a difference that is produced by placing an insulating layer. The scenario DB (Greenhouse on the structure of scenario B) and DC (Greenhouse on the structure of scenario C) fell by 40% in summer demand on the stage A, but during winter shows no savings in heating demand. Scenario C shows a 29% savings over the winter.

Figure 4 shows the total annual demand for heating and cooling inside the building. Scenario C shows a 42% annual savings compared to scenario A. The scenario D has a 22% savings.

Note that this a first approach to the RTG study, and other strategies than can favour RTG performance, such as shading and evaporative cooling have not been consider.

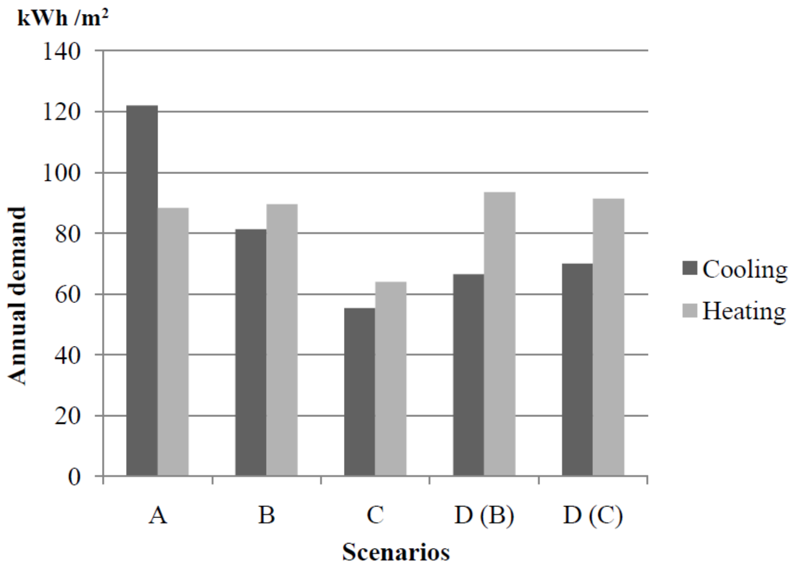

Fig.4: Annual demand of heating and cooling inside the building

Table 3 presents the results of CO_2 equivalent in the use stage associated with each of the scenarios under study.

Tab.3: The results of the CO_2 equivalent emissions associated with each of scenarios

Annual emission	Scenarios				
	A	**B**	**C**	**D (B)**	**D (C)**
$kgCO_2$ eq/m^2	126.17	102.48	71.61	95.94	96.83

It can be seen that C prevent 43% of CO_2 emissions compared to scenario A, while in scenario D (B) only achieved a reduction of 24%

5 Discussion

Results presented indicate that the RTG system with no interconnections between greenhouse and building has no significant benefits associated with building energy savings. Presents values slightly inferiors to conventional insulation systems.

Food production in cities has the additional advantages of avoiding the energy and GHG associated with long distance food transportation (for this case study from Almeria to Barcelona), as well as improving the quality of food within households and promoting sociability.

If buildings and food production could be interconnected, potential benefits from economic, environmental and social points of view could be achieved.

RTG with a new interconnect technology solution can reduce the carbon footprint of horticultural products by using waste energy and gray water flow in urban areas and minimizing the distance between producers and consumers.
They require new technologies for the interchange of fluxes. Moreover, innovative and specific control systems are needed for managing the greenhouse-building combination.

Currently we are continuing to research by CFD (computational fluids dynamics) to optimize the operation of the interconnections in this system. At the same time is expanding the study to the entire life cycle of building materials.

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