Potential environmental and economic benefits from local food production in Mediterranean rooftop greenhouses

GROOF PROJECT

28/11/2017

Gara Villalba (UAB) //Susana Toboso (UAB) // Mireia Ercilla-Montserrat (UAB)// Ana Nadal (UAB)// Maria Rosa Rovira (UAB) // Alejandro Josa (UPC) // Juan Ignacio Montero (IRTA) // PhD Isabel Pont // **Xavier Gabarrell (UAB)** // Joan Rieradevall (UAB) // Alejandra Peña //PhD Mario Giampietro // MSc Perla Zambrano // MSc Ana María Manríquez//

CTM2016-75772-C3-1-R, AI/UE-Feder

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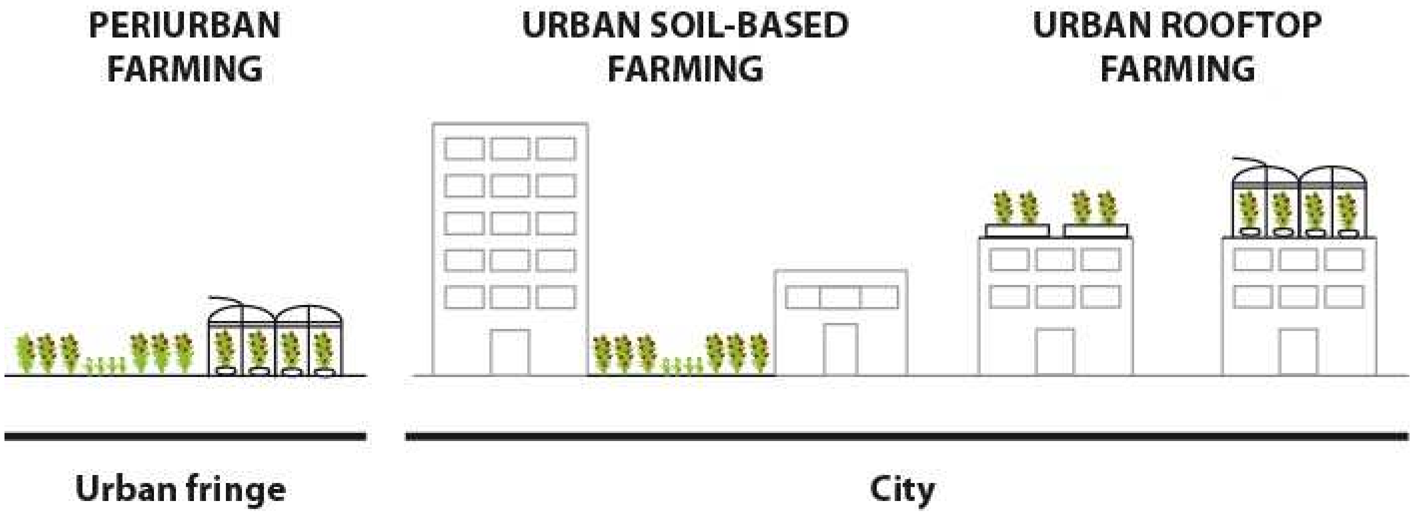
Content

1.2. Vertical farming



Our case study

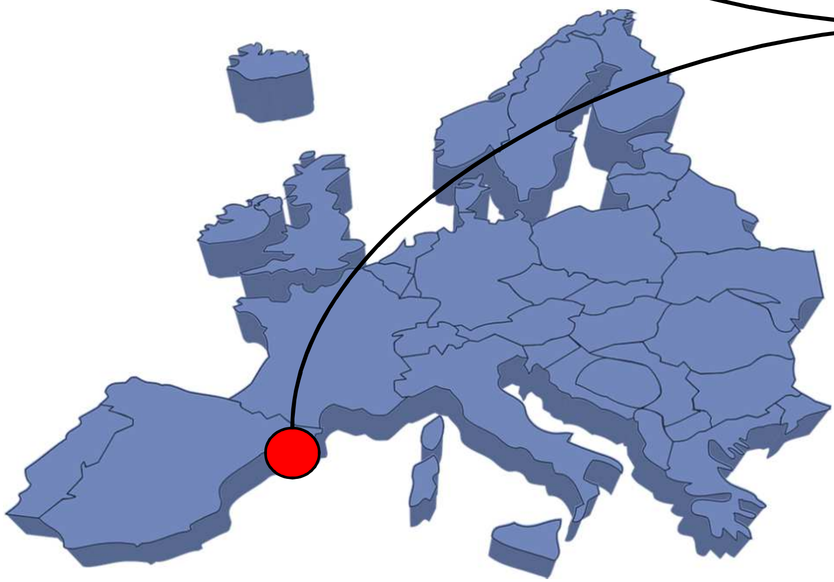
The Rooftop Greenhouse Lab

(i-RTG-Lab)

New building ICTA-ICP (UAB)
May 2014 - Bellaterra, Barcelona

1st integrated RTG in Spain

1.2. Vertical farming



Integrated Rooftop Greenhouse Lab

New building ICTA-ICP (UAB)
May 2014 - Bellaterra. Barcelona

1st integrated RTG in Spain

2. Case study

Ecodesigned and sustainable building (2014)

The Rooftop Greenhouse Lab
(i-RTG-Lab)

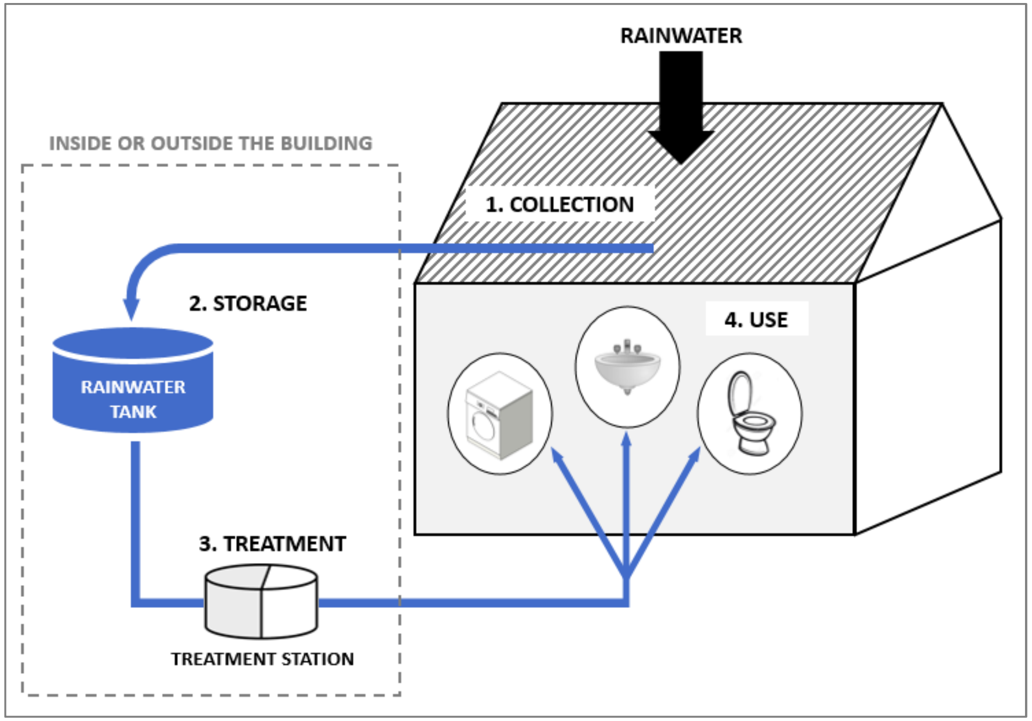
New building ICTA-ICP (UAB)
May 2014 - Bellateρra, Barcelona

1st integrated RTG in Spain

Water scarcity and water-saving technologies

Water-saving technologies can represent an alternative to increase the self-sufficiency of urban areas.

Rainwater harvesting systems



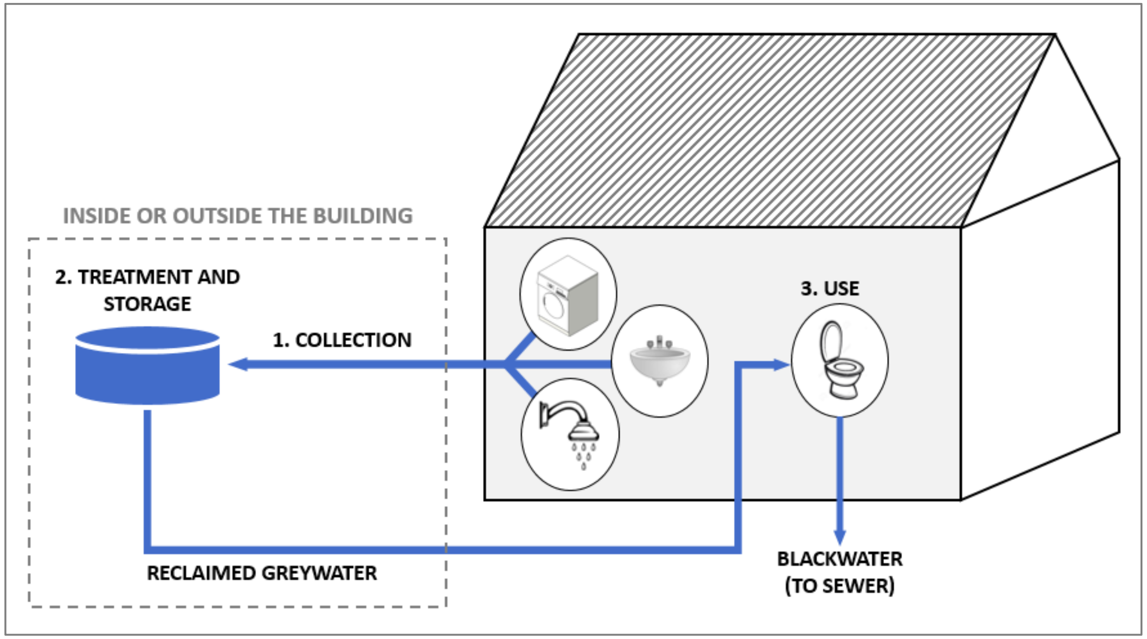
- Consists of the **utilization of rainwater** to fulfil the water demand.
- Increases the **self sufficiency** of the system.
- Previous studies proved it can be **economically and environmentally advantageous** [1], [2].

2. Case study

Water scarcity and water-saving technologies

Water-saving technologies can represent an alternative to increase the self-sufficiency of urban areas.

Greywater reclamation systems

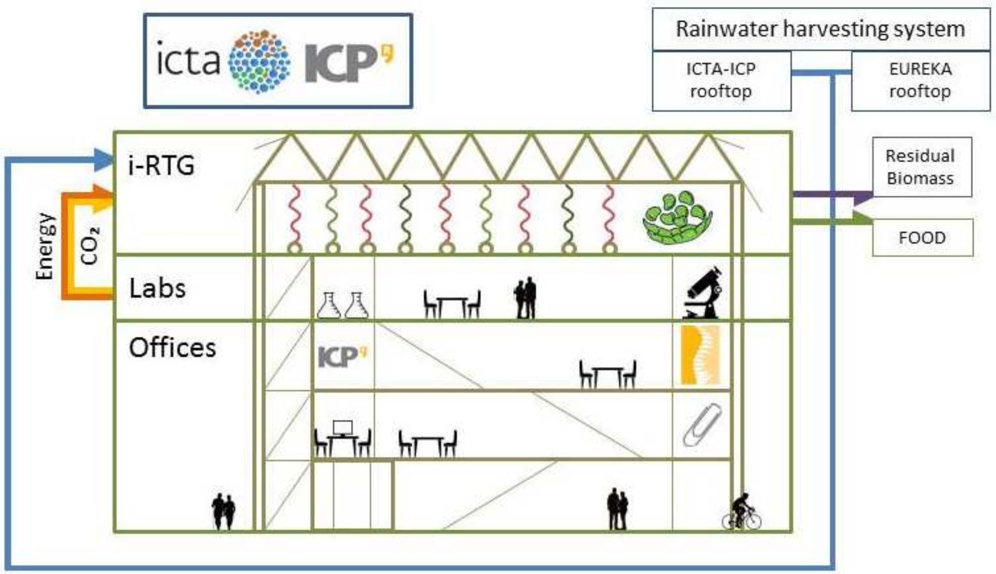


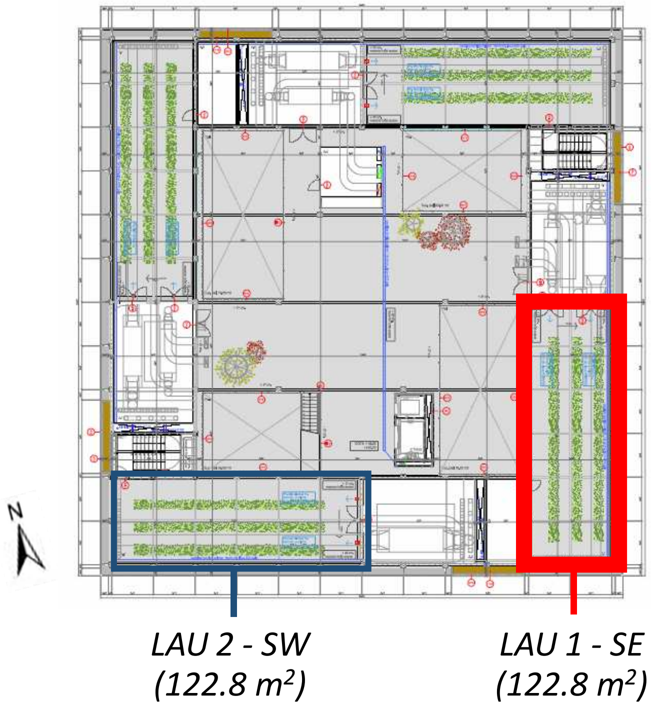
- Consists of **reusing greywater** (usually from washing hands or showers) for other uses requiring less quality, such as flushing toilets.
- **Reduces the volume of wastewatewater** generated.
- **Reduces the external water demand** of the system.

i-RTG-LAB

In contrast to conventional RTG projects. the RTG-Lab is an Integrated RTG (i-RTG) that exchanges the residual flows (**residual heat**, **rainwater** **and** **CO_2**) with the ICTA-ICP building.

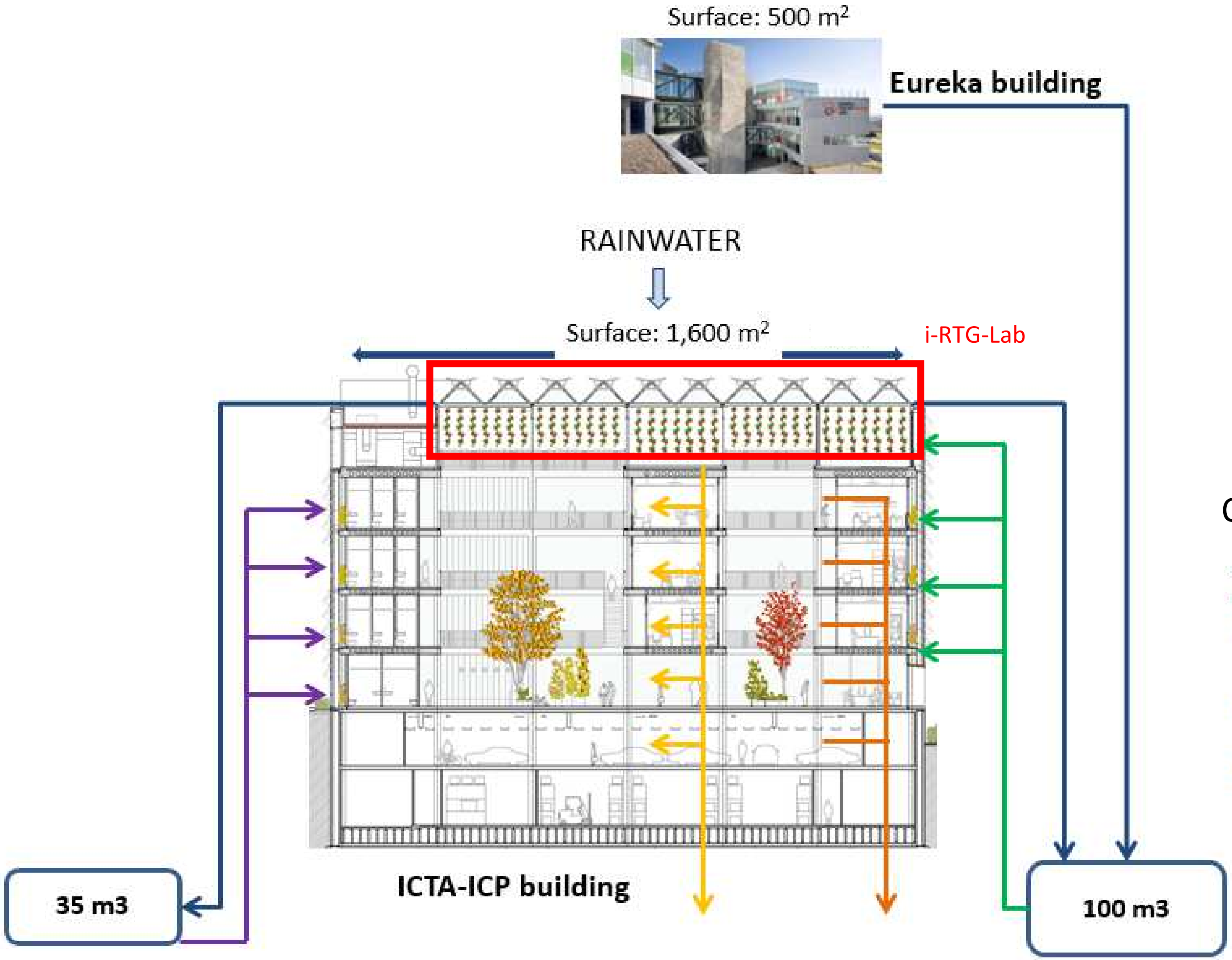
Different crops have been cultivated: tomato, lettuce… and bean**.**





2 i-RTGs (122.8m² each, with 84.34m² for the crop)

2. Case study



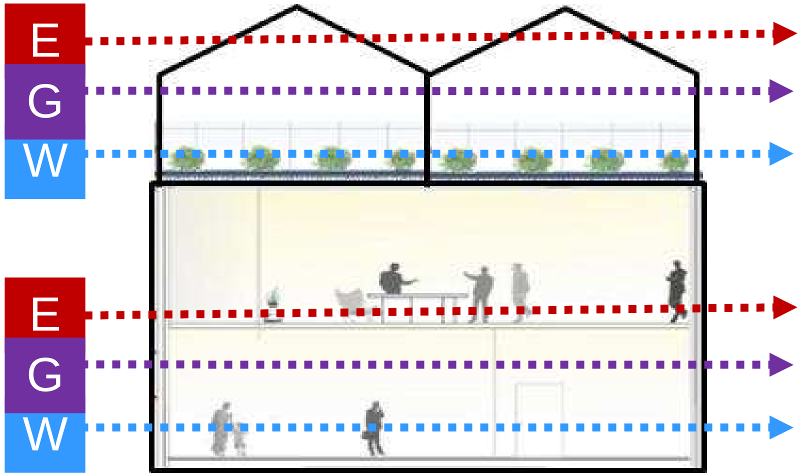
Quantified water flows:

- Rainwater supply
- Irrigation
- Water for toilets and washing machines
- Potentially usable wastewater from RTG-Lab
- Wastewater from toilets and washing machines

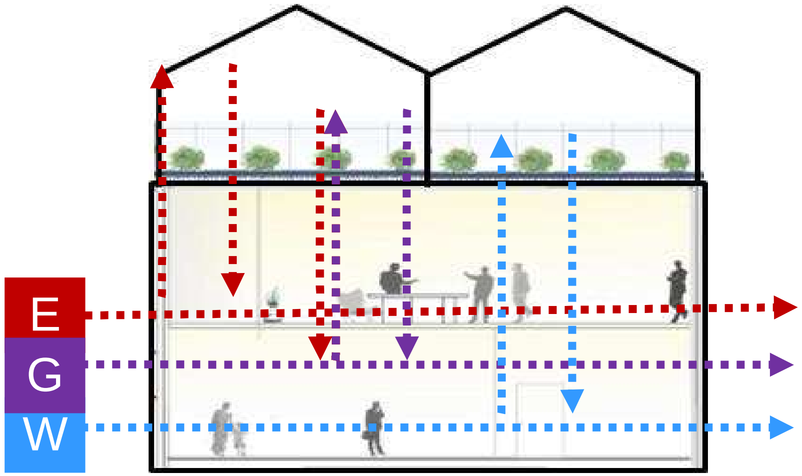
2. Case study

In contrast to current RTG projects, the ICTA -iRTG is an **Integrated RTG (iRTG)** that exchanges the metabolic flows with the ICTA-ICP building

Isolated RTGs

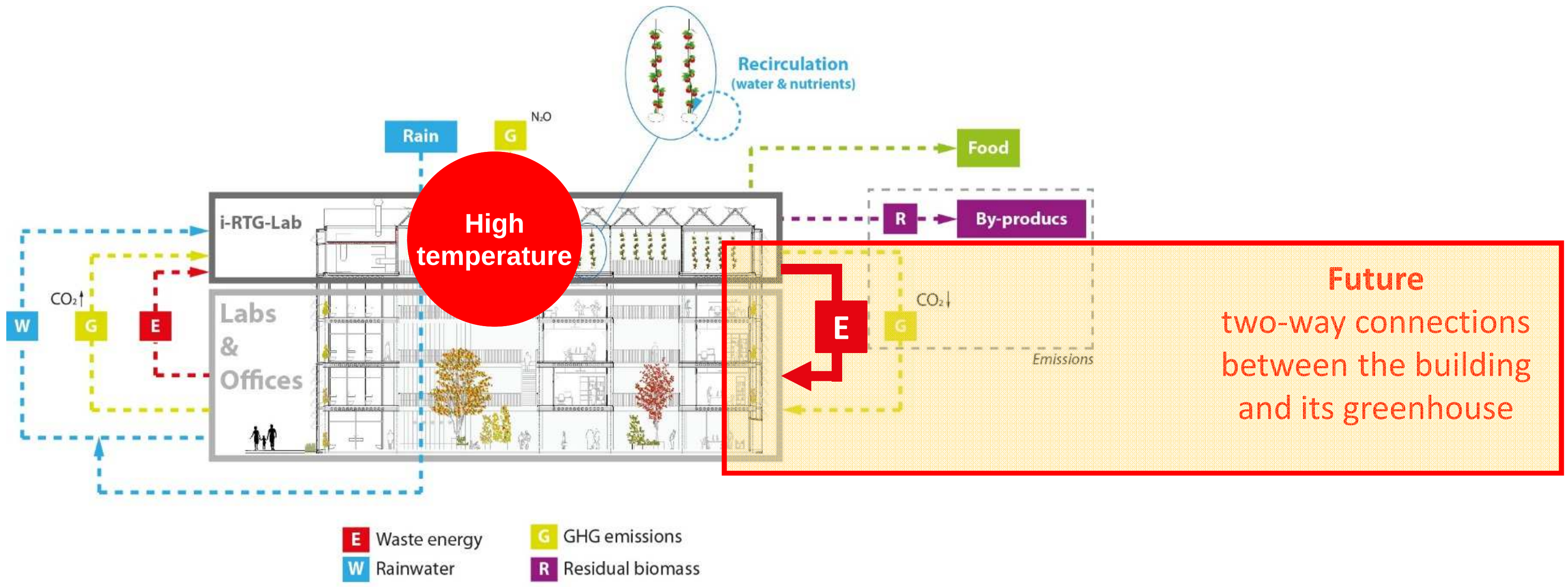


Integrated RTGs
(Ideal model)



Currently: unidirectional model

Building-integrated rooftop greenhouse



In winter: Use of residual hot air accumulated in the i-RTG, which needs to be ventilated, to heat the building.

1. http://www.fertilecity.com

2. Case study

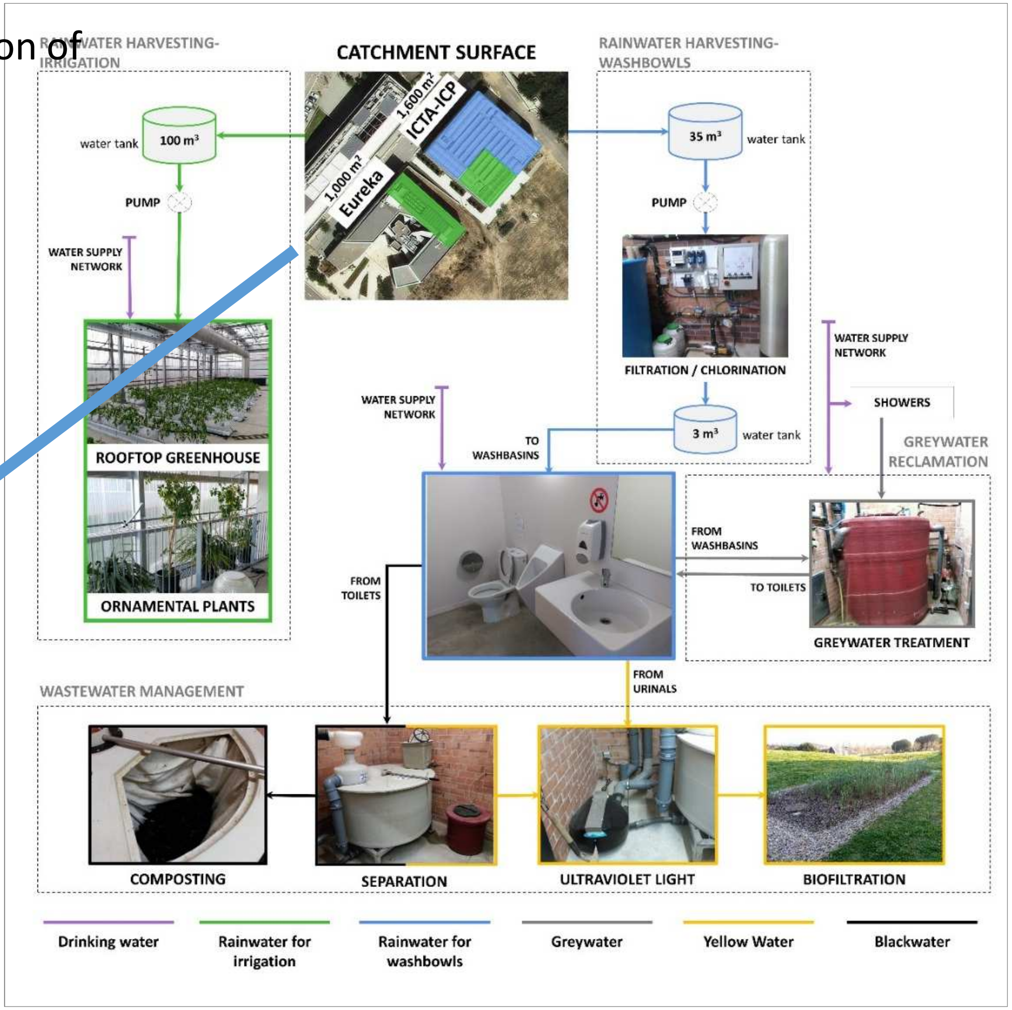
Current strategies for water saving in the ICTA-ICP building

- ❖ Minimisation of the water demand
  - Washbowls
  - Irrigation of ornamental plants
- ❖ Use of harvested rainwater
  - Rainwater for domestic uses
  - Rainwater for irrigation
- ❖ Reuse of greywater
  - Flushing toilets

2. Case study

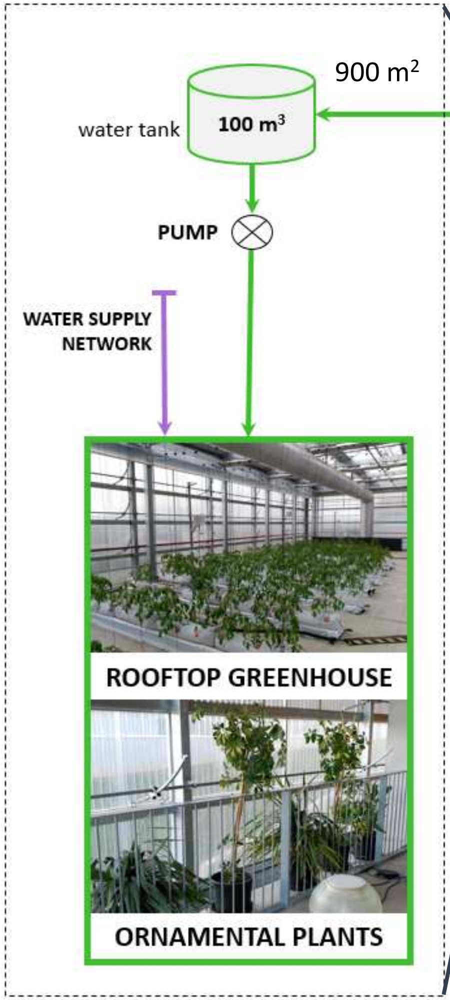
Description of the study system and quantification of the flows

- All water-consuming points are connected to the water supply network to ensure supply.
- The total external demand for water from the water supply network was measured (flow meter).

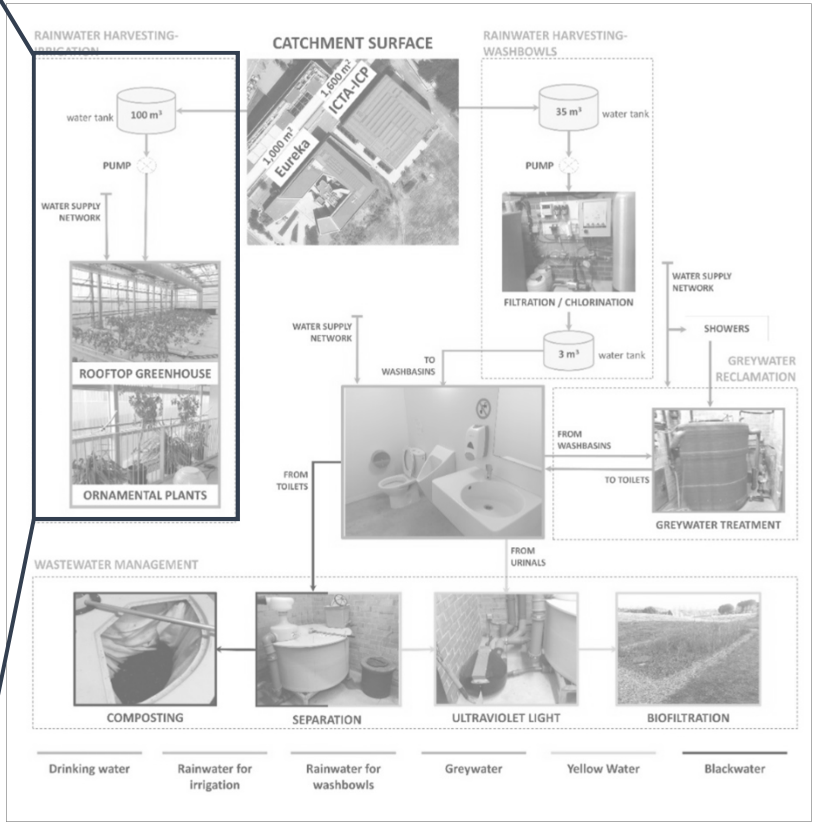


2. Case study

RAINWATER HARVESTING - IRRIGATION



Description of the study system and quantification of the flows

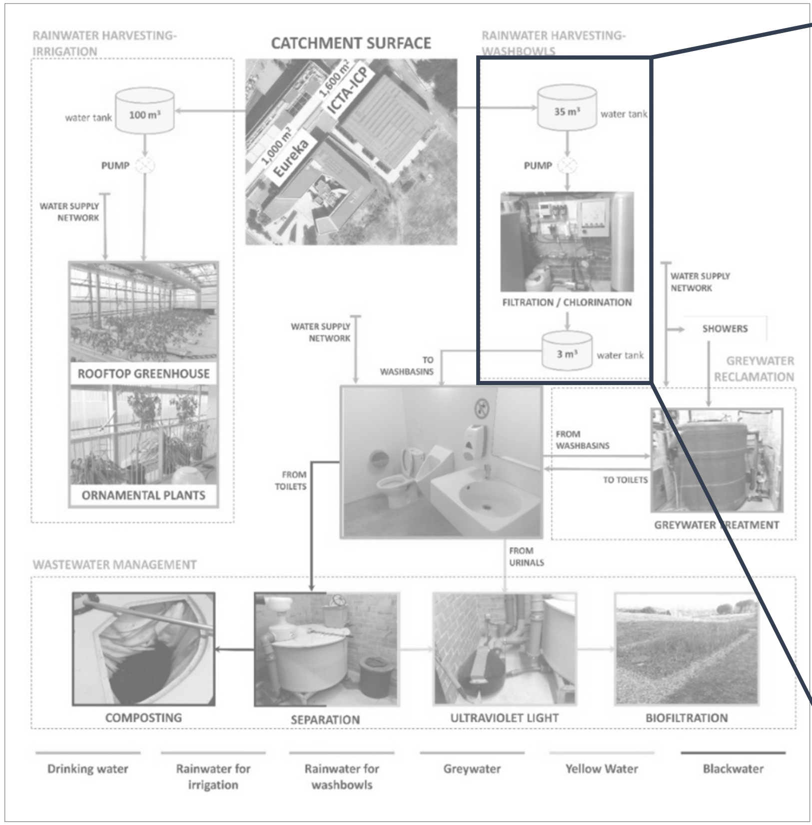


- Catchment surface:
  - •500 m² Eureka roof
  - •400 m² ICTA-ICP roof
- Water for irrigation in the greenhouse was measured (flow meters).
- Water for watering ornamental plants was estimated (blueprints, staff in charge, direct observation).

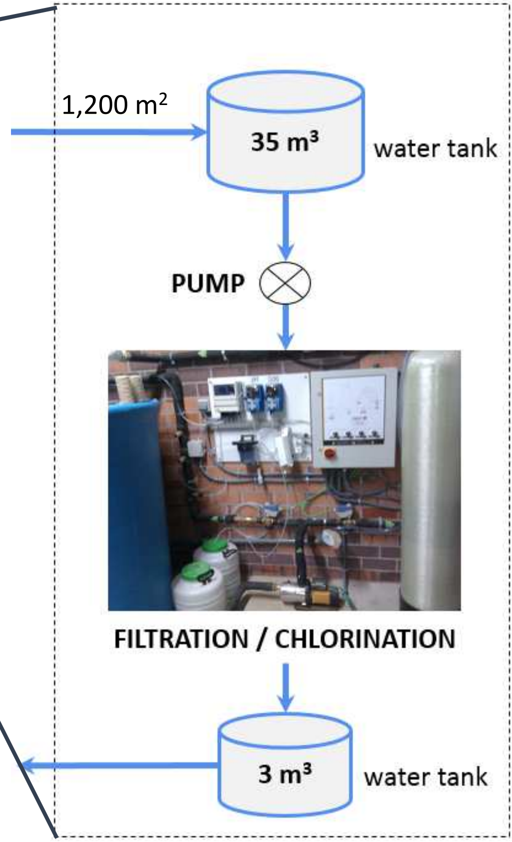
2. Case study

- Catchment surface:
  - •**1,200 m²** ICTA-ICP roof
- **Rainwater used in washbowls was measured** (flow meter).

Description of the study system and quantification of the flows



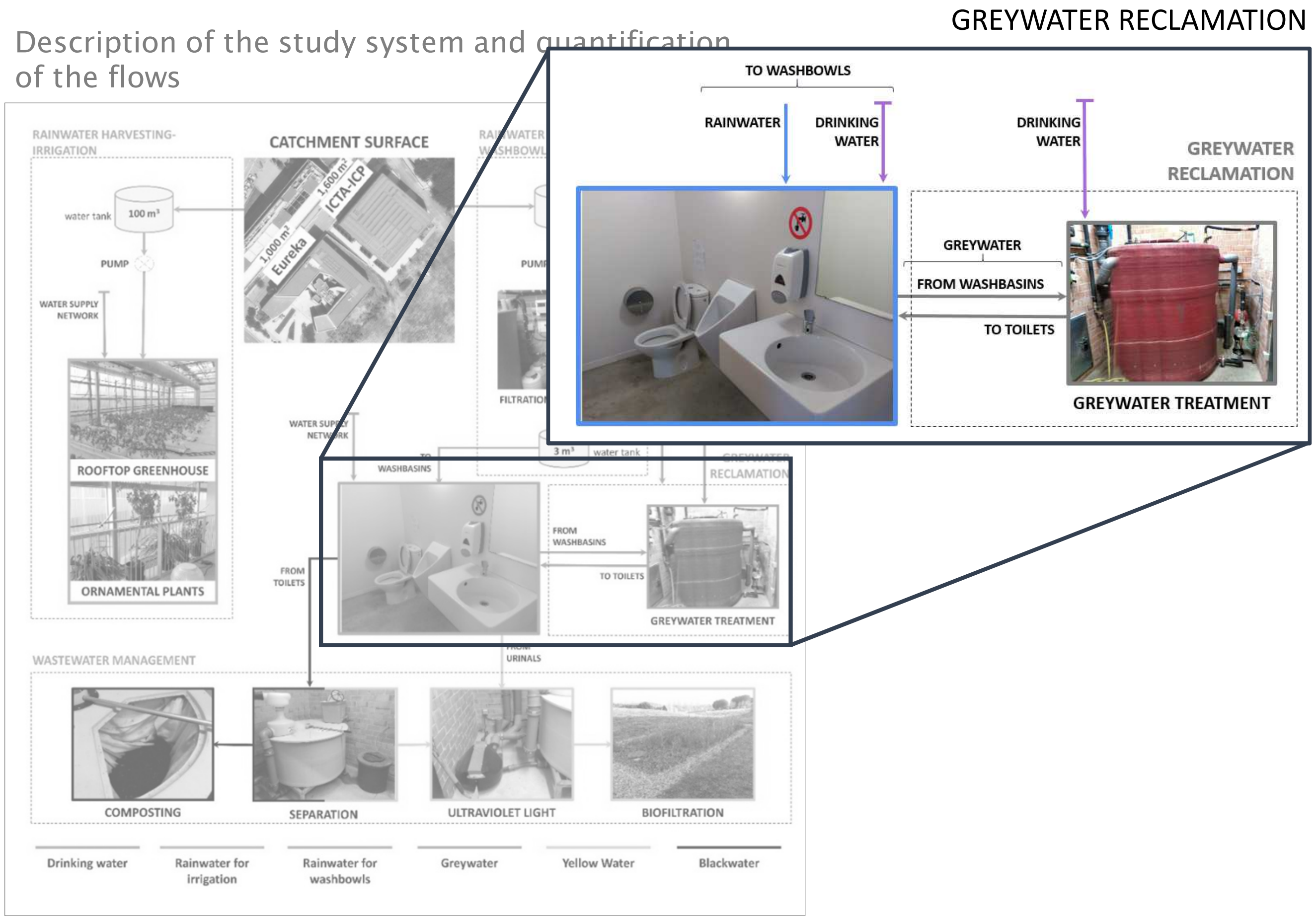
RAINWATER HARVESTING - WASHBOWLS



2. Case study

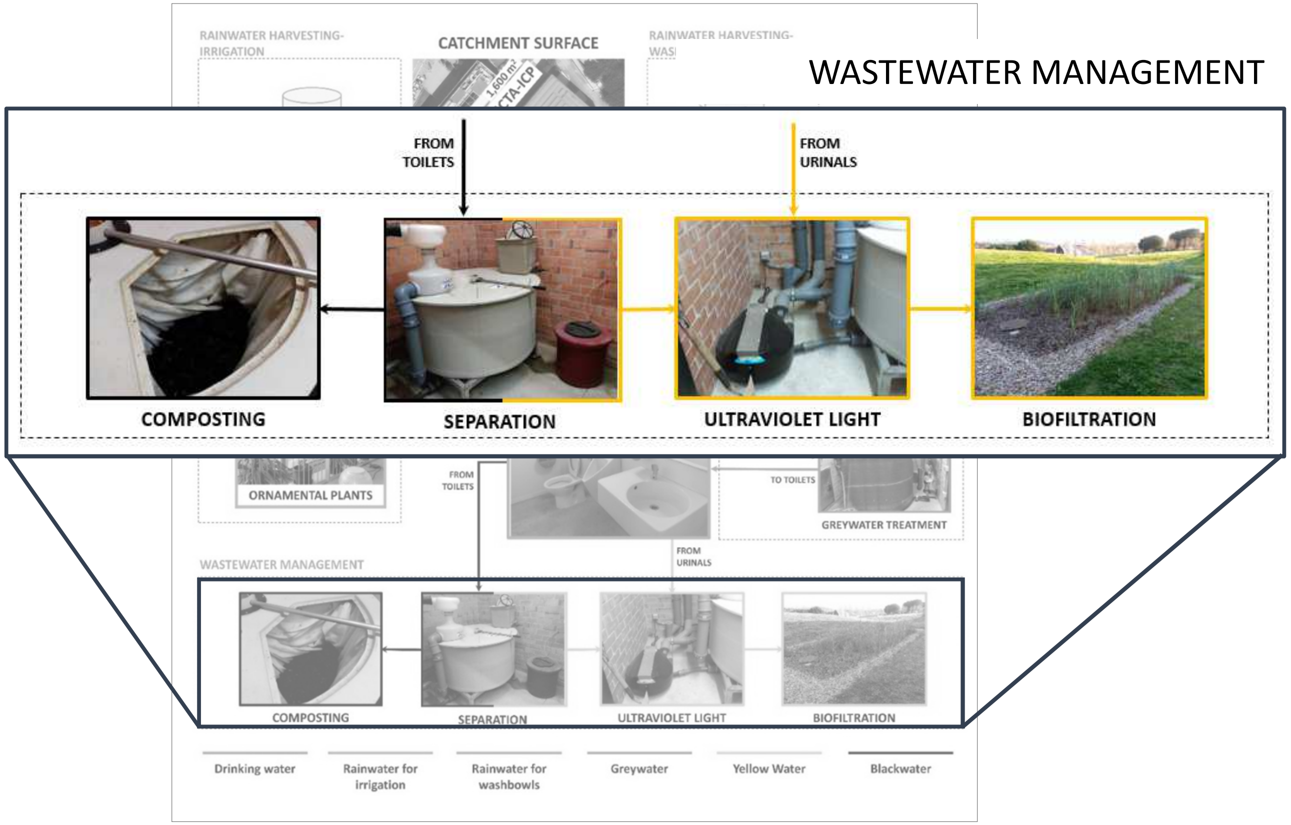
- 2 greywater treatment stations:
  - NW station
  - SE station
- Total outflow SE station: measured (flow meter)
- Total outflow NW station: estimated (working spaces)

Grey water = rainwater (measured) + water from showers (estimated)



2. Case study

Description of the study system and quantification of the flows



3. Objectives

General

- Demonstrate the **technical**, **environmental** and **economic** feasibility of producing food in i-RTGs in Mediterranean cities.

Specific

- Elaboration of a **Life Cycle Inventory (LCI)** - Data collected: water, energetic and CO_2 flows for the of the i-RTG-Lab

- Quantification of the environmental and economic advantages of:

  - Using **rainwater** to irrigate the crop

  - Using **waste air and thermal inertia** of the building to warm the greenhouse.

  - Quantification of **CO2 residual** flow

- Perform a comprehensive and integrated assessment of the implementation of URF to **provide further knowledge** for supporting decision-making processes for planners, designers or practitioners

4. Materials & methods

CROP ANALYSIS AND CHARACTERIZATION

Other methods		
Analysis	Freq.	Materials
Temperature	Once per hour - every 10’	SIEMENS
Relative humidity	High frequency	CAMPBELL SCIENTIFIC WHEN MEASUREMENTS MATTER
Production	Twice a week*	Manual + scales

**during the harvesting period*

Methods

pH, Ce: daily analyses

Anions and cations:

3 analyses /week

Materials

Water flowmeters

- Soil-less culture system
- Substrate: perlite
- Automatic irrigation with NPK nitrogen (N), phosphorus (P) and potassium (K).
- Crops: lettuce, tomato

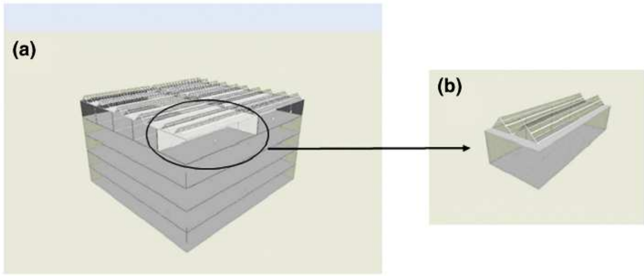
4. Materials & methods

In collaboration with: Newcastle University

(a) To report the measured **annual** data that outlines the **symbiosis** between the **ICTA-iRTG** and **the building** in **energy** terms

(a) Using computer simulation to **quantify** the **heating energy** that ICTA-iRTG has passively and actively recycled from the ICTA-ICP.

A. Nadal et al. / Applied Energy 187 (2017) 338–351



(a) Design Builder model of the ICTA-ICP building to validate model prediction accuracy, (b) freestanding iRTG used to examine freestanding greenhouse conditions.

Methodology

- Data acquisition: Campbell & Siemens sensors
- Energy simulation: Designbuilder & Energy Plus
- Sampling period: 2015
- Sampling place: ICTA iRTG
- Campbell data acquisition system
- Siemens data acquisition system

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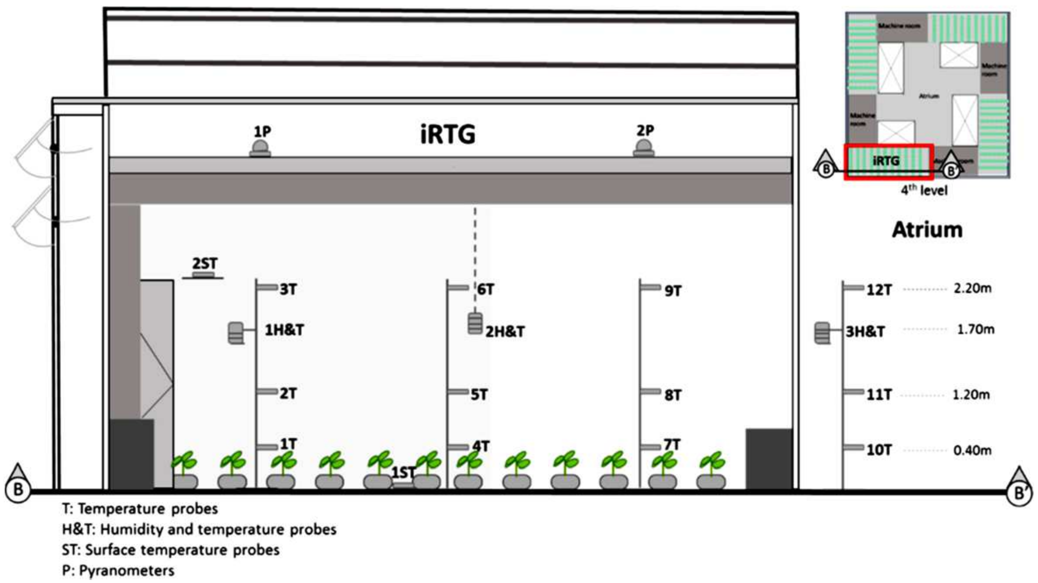
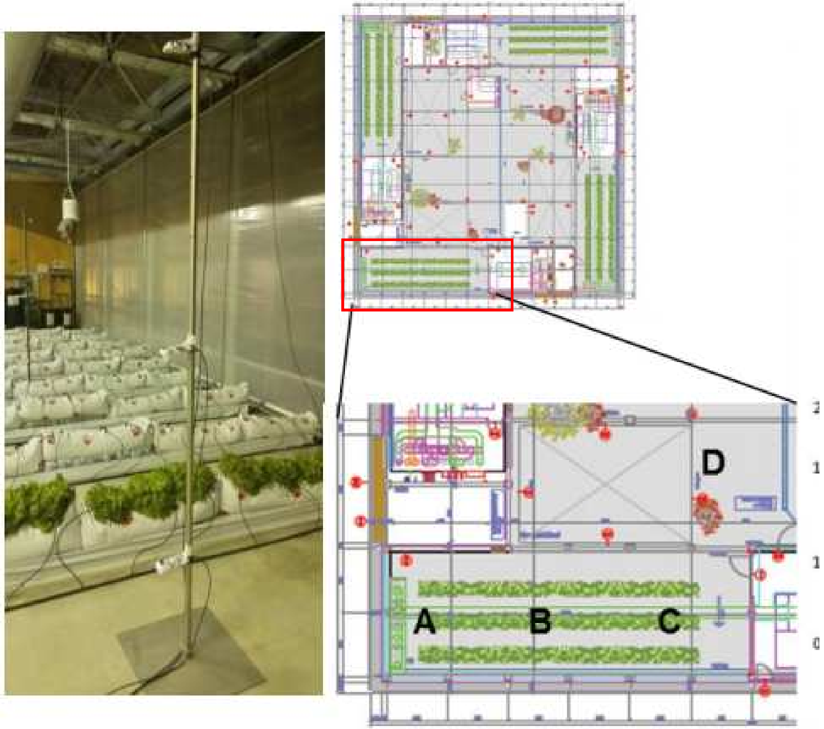


4. Materials & methods

Monitoring control



Location sensors for energy monitoring

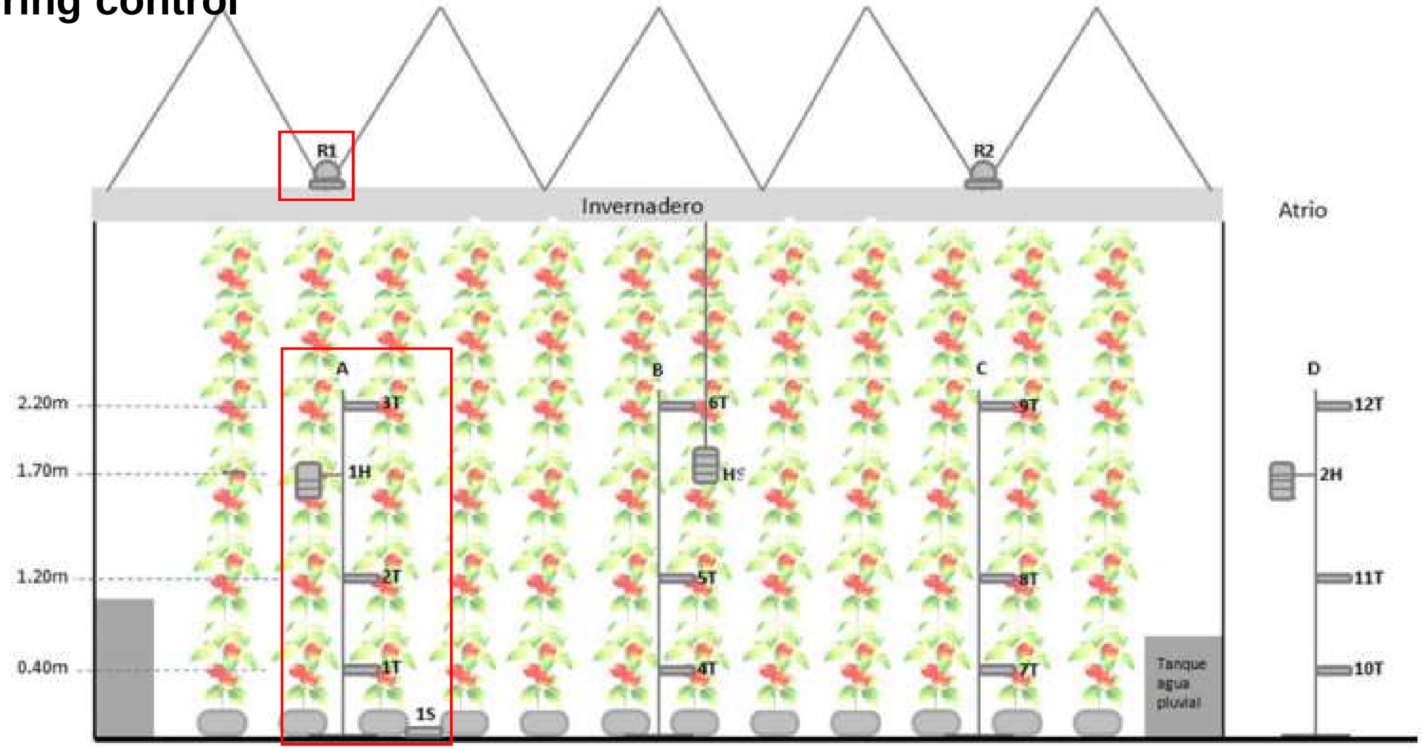
The greenhouse and outdoor environments are monitored in terms of temperature and other climatic variables (T/ %RH probe. It also has air velocity, solar radiation and heat flow sensors, among others).

Indooor Sensors :
16 Temperature sensors *(107 Campbell)*
3 Humidity and temperatura sensors (*CS215 Campbell*)
2 Pyranometers (*LP02 Campbell)*
2 Surface temperatura sensors *(110 PV Campbell)* coming soon

Outdooor Sensors :
ICTA Building sensors (SIEMENS)

4. Materials & methods

Monitoring control



Location sensors for energy monitoring

The monitoring design consists of instruments uniformly distributed inside the ICTA-iRTG and in other spaces of the rooftop level of the building, which are located at four vertical supports and each vertical support has 3 temperature probes.

Measurements are taken every 5 seconds and an average is done every 10 minutes.

4. Materials & methods

Quantification of the water flows

A period of 331 days (11 months) was considered for the analysis, from 21/05/2015 to 15/04/2016.

Application of the Plugrisost software

The software was used to estimate the optimal size of the rainwater tank used to supply washbowls and the potential demand that could fulfil.

Data of precipitations for 7 years in the UAB was considering, using average values from the 7 years.

4. Materials & methods

Life cycle assessment*

Goal and scope

Goal and scope definition

Inventory

Inputs and outputs data compilation

Impact assessment

Classification
Characterization

SimaPro ecoinvent

Interpretation

Interpret the results

FU	1 kg of edible beans produced in the ICTA-ICP i-RTG

CROP ANALYSIS AND CHARACTERIZATION

Periodic methods		
Analysis	Freq.	Materials
pH	diary	pH sensor
Ce	diary	Ce sensors
Fertilizers - leachates	3 per week	Ion Chromatography
Water entrance	diary	Flowmeters

Analysis at the end of the crop

Substrate (Perlite)
Residual biomass (leaves, stem and roots)
Bean (fruit)

Other materials

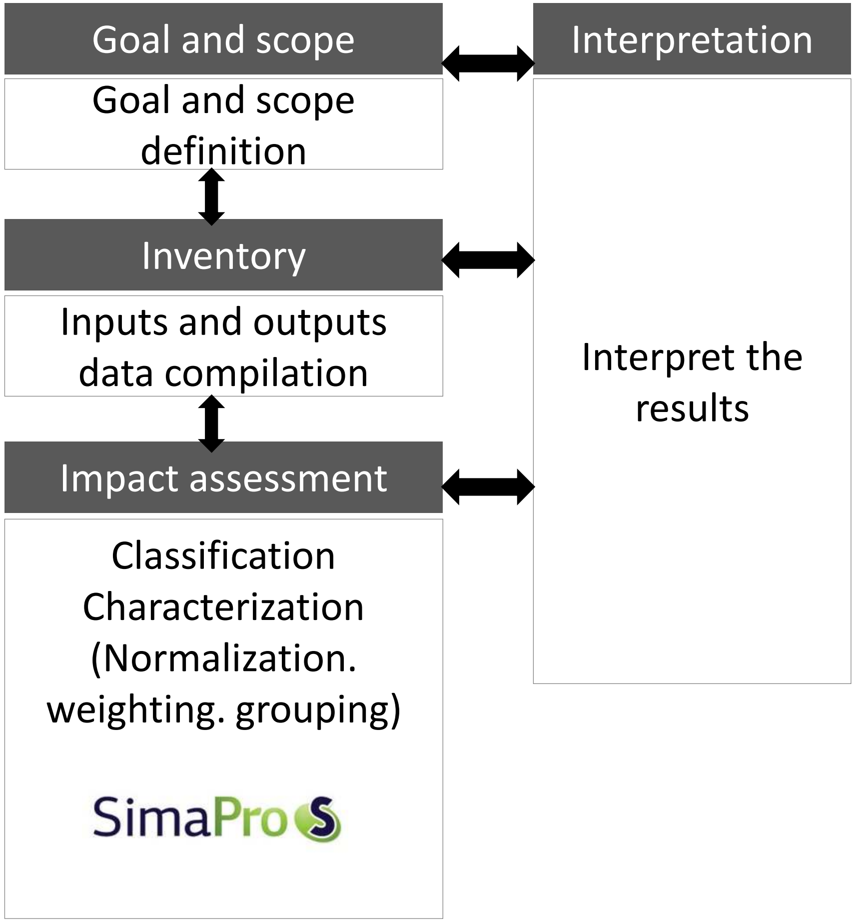
Atomic Spectroscopy
Elemental Analysis

Follow-up by agronomic experts

ISO (2006a) ISO 14040. n.d. Environmental management — Life cycle assessment — Principles and framework Management environnemental — Principles and Framework. Int. Organ. Stand.

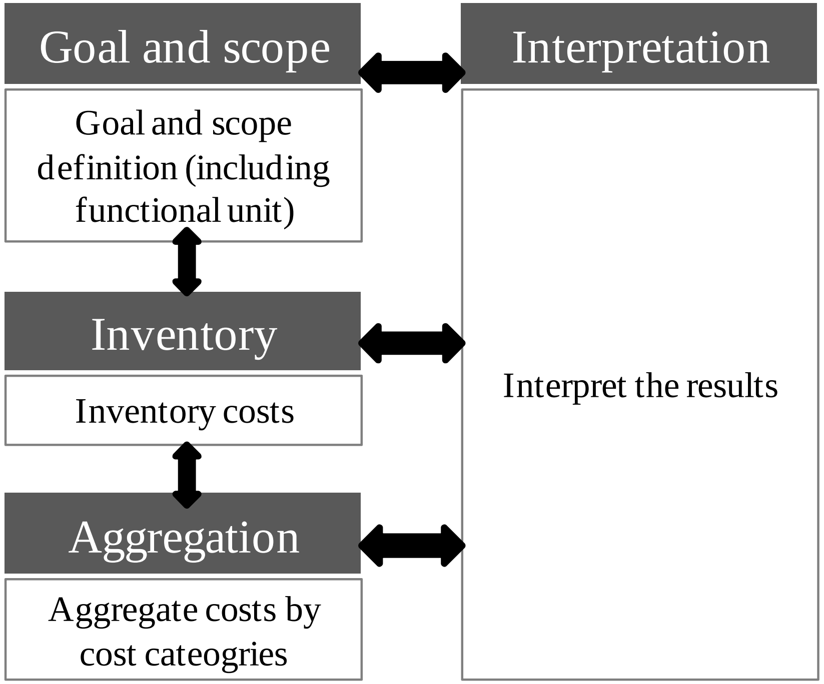
4. Materials & methods

Life cycle assessment



ISO 14040-44 *(ISO 2006a, 2006b)*

Life cycle costing

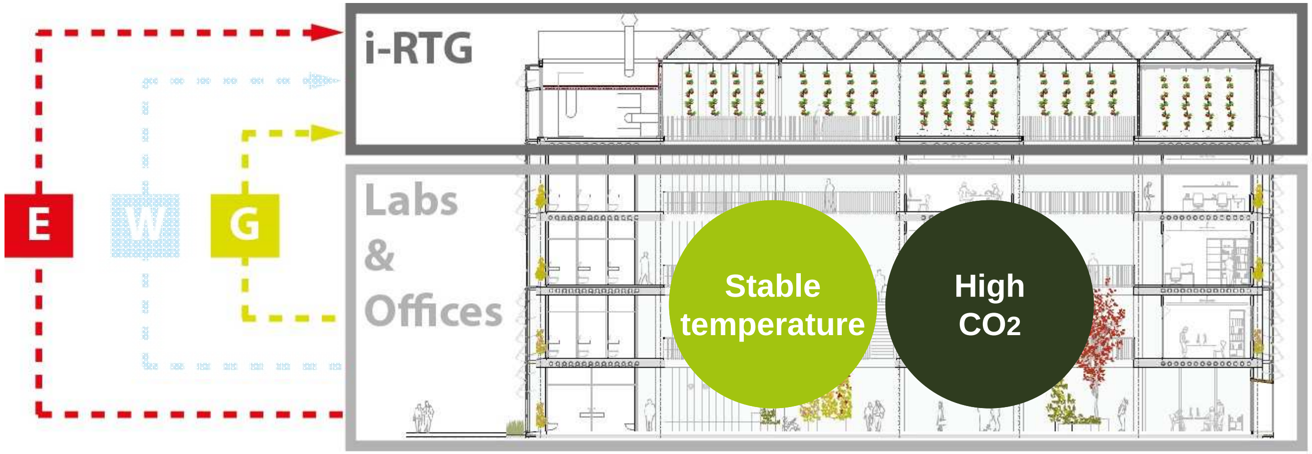


ISO 15686-5 *(ISO 2008)*

5. Results. The i-RTG LAB

4. Materials & methods

Building-Greenhouse Interconnection



Materials

CO_2 sensor

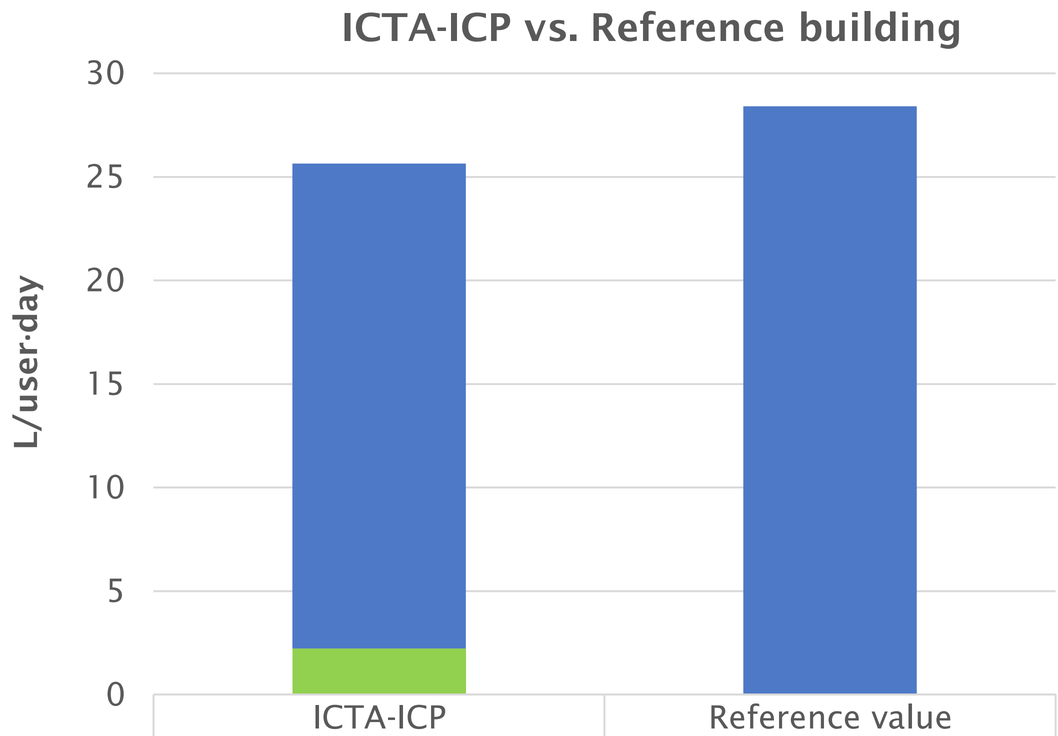
Air flowmeter

Temperature thermistors

Daytime	Conventional production	i-RTG-Lab
Day	Extreme temperatures for crop production (>35ºC), particularly in summer	Building → **Cold air** → Greenhouse
Night	Extreme temperatures for crop production (<15ºC), particularly in winter	Building → **Waste heat** → Greenhouse
Day	CO_2 is injected to supply crop demand to enhance photosyntesis and crop yield	Building → **CO_2** → Greenhouse

5.1. General results

Overall water use efficiency of the building



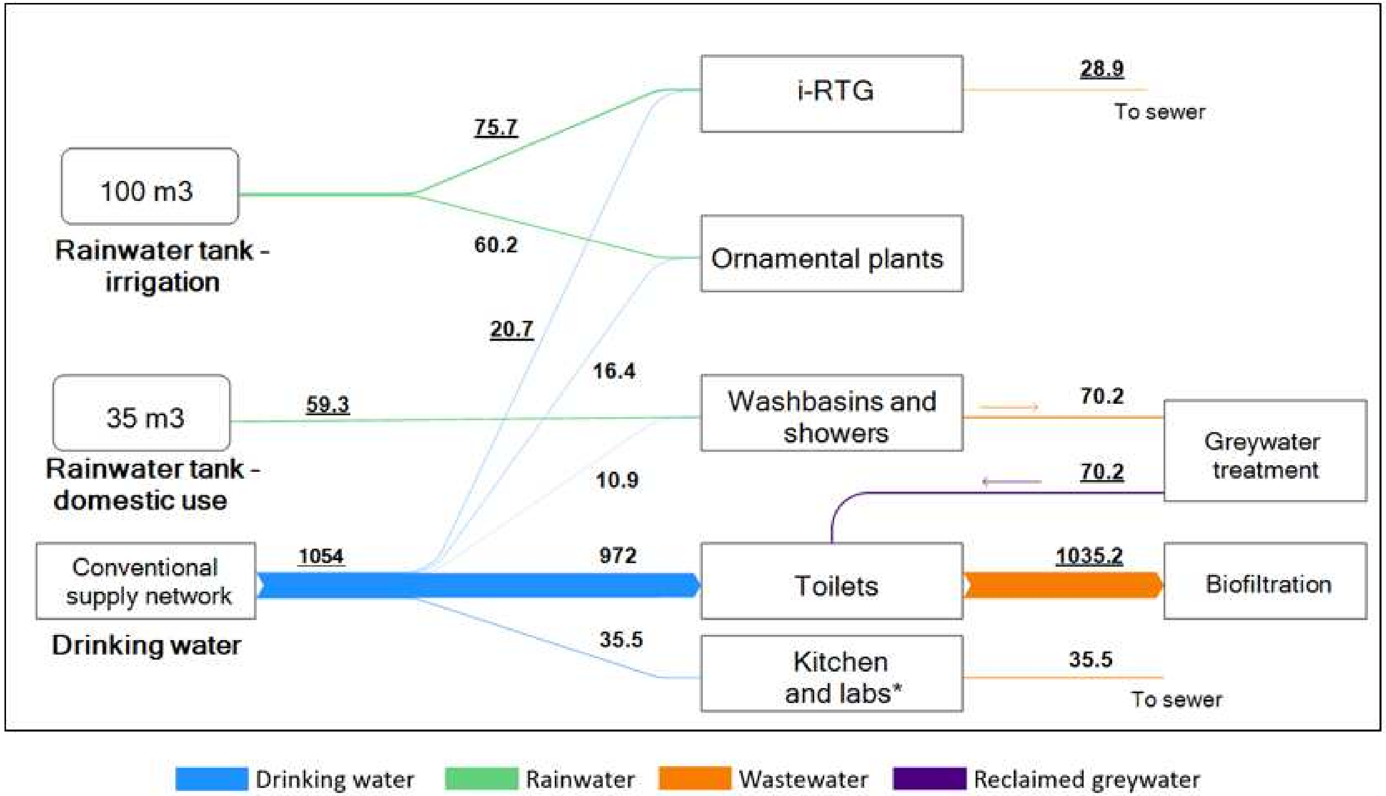
	ICTA-ICP	Reference value
Drinking water	23,41	28,4
Rainwater	2,23	

- ICTA-ICP is more efficient in the use of water than the reference building:
  - **Water demand 10% lower**
  - **External water demand 18% lower**
- However, **a higher efficiency would be expected** according with the potential of rainwater harvesting and greywater reclamation systems studied in previous literature.

5.1. General results

Quantification of the water flows

Water flows in the building



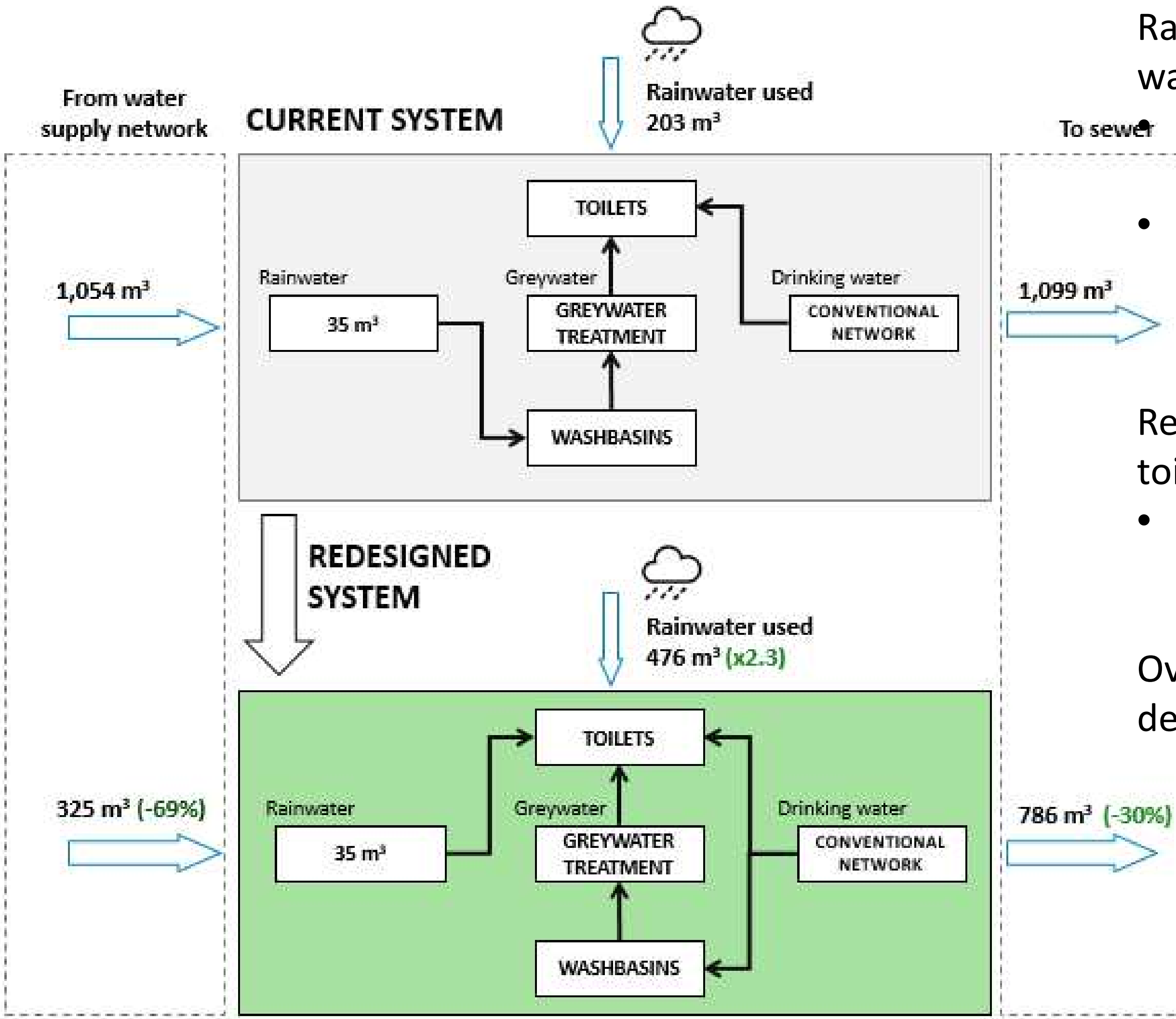
Underlined figures were experimentally measured.

- Largest water-demanding element in the building: **flushing toilets**
- The **water demand of toilets is mostly fulfilled with drinking water** from the water supply network.

  (972 m^3, 92% of the total external demand)
- The rainwater harvesting system with the **35 m^3 tank is underused** (low demand of washbowls).

5.1. General results

Proposal for the redesign of the network



Rainwater used in toilets instead of washbowls

- Better utilization of rainwater collected (203 m³ → 476 m³)
- Avoids filtering and chlorination (washbowls use drinking water)

Reduction of the discharge volume of toilet cisterns

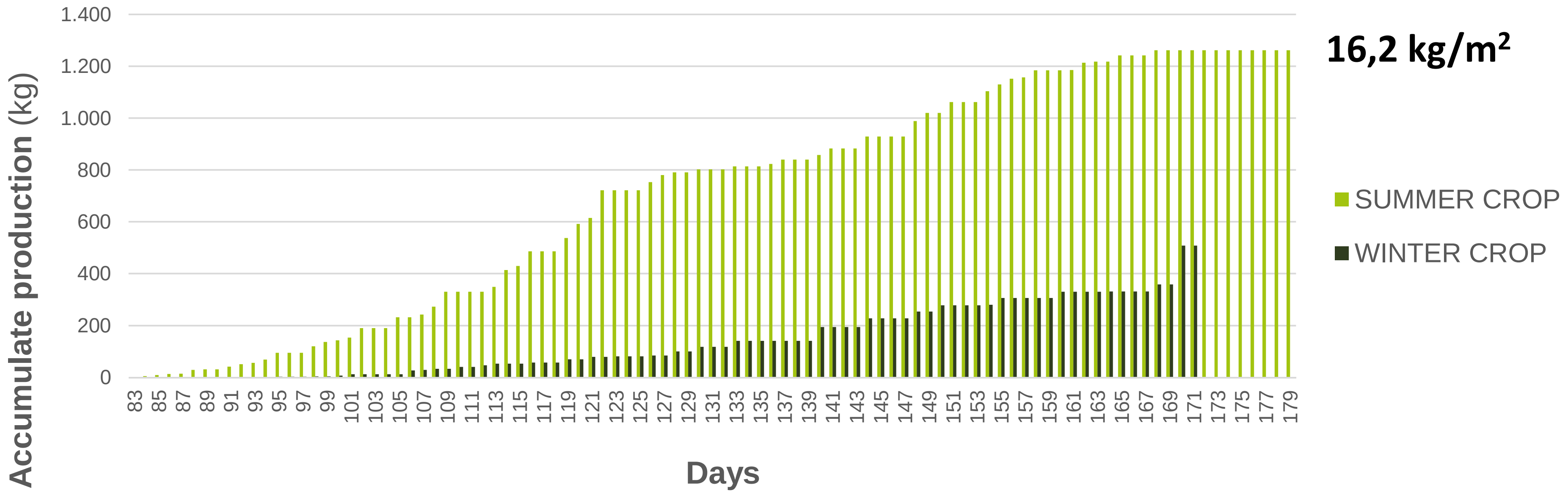
- Reduces drinking water demand and the wastewater volume by 30%.

Overall reduction of 69% of the demand for drinking water

5. General results

Tomato production

Comparative graph the first and second tomato crop (i-RTG-Lab)



16,2 kg/m²

5.1. General results

Water

LCI of water consumption for summer and winter crops

	Summer (L/m²)	Winter (L/m²)	Total (L/m²)	Avoided CO_2 (kg CO_2 eq./m²·year)	Saved costs (€/m²·year)
Total water for irrigation	974.26	457.37	1431.63	0.3	3.5

- **60% of rainwater** used in the summer crop
- Nearly **100% in the winter crop**
- **$1.1 m^3/m^2$·year** of tap water could be **saved**

5.2. General results

Energy

LCI of annual energy saving of the i-RTG-Lab

	Heat (kWh/m^2·year)	Avoided CO_2 (kg CO_2 eq./m^2·year)	Saved costs (€/m^2·year)
Energy saving	387	99.4	19.65

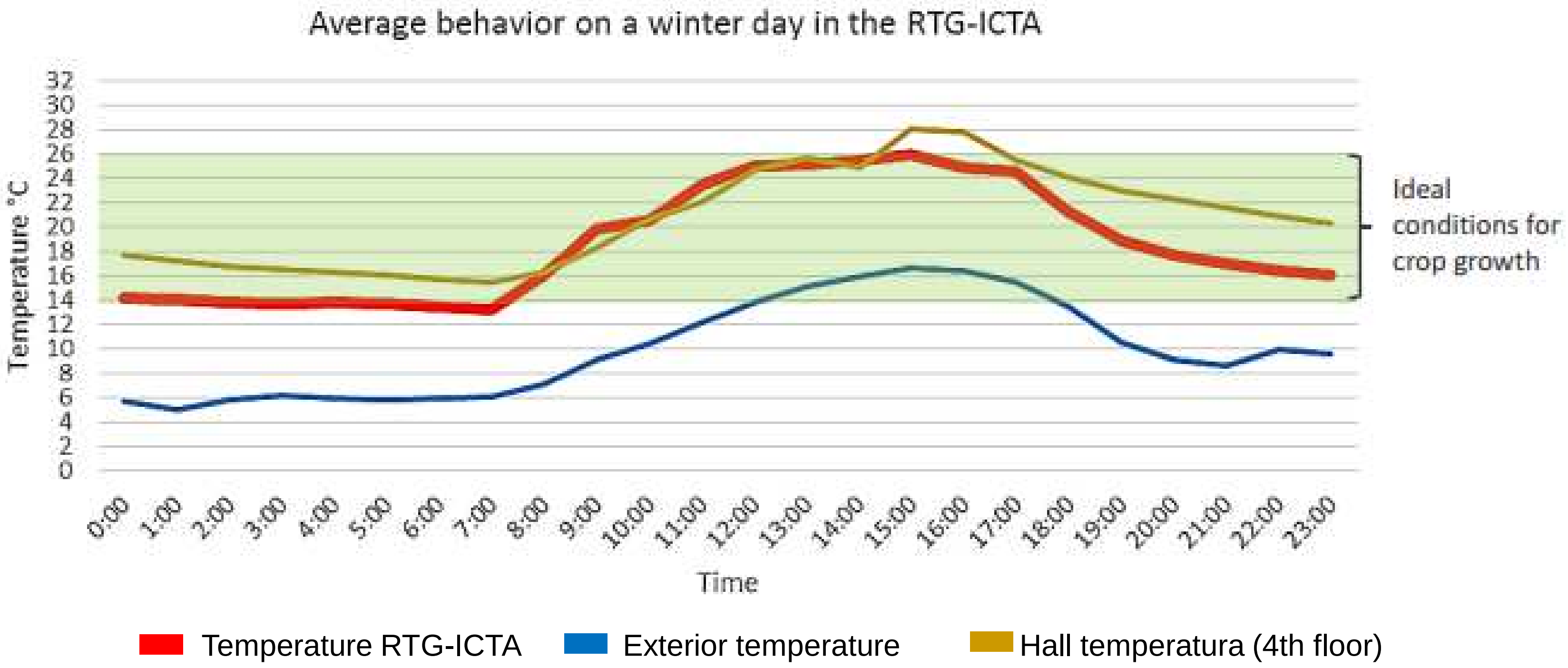
- Average temperature difference inside-outside: **9 degrees**
- The thermal inertia of the building keeps the i-RTG-Lab warm (**above 14º C**) during cold periods
- **No heating** systems are required
- **Winter crops** could be feasible

5.2. General results

Results

Energy efficiency of buildings metabolism for local food production

Winter: average day



The RTG-ICTA night temperatures differ an average of 10 ° C compared to temperatures recorded outside the building.

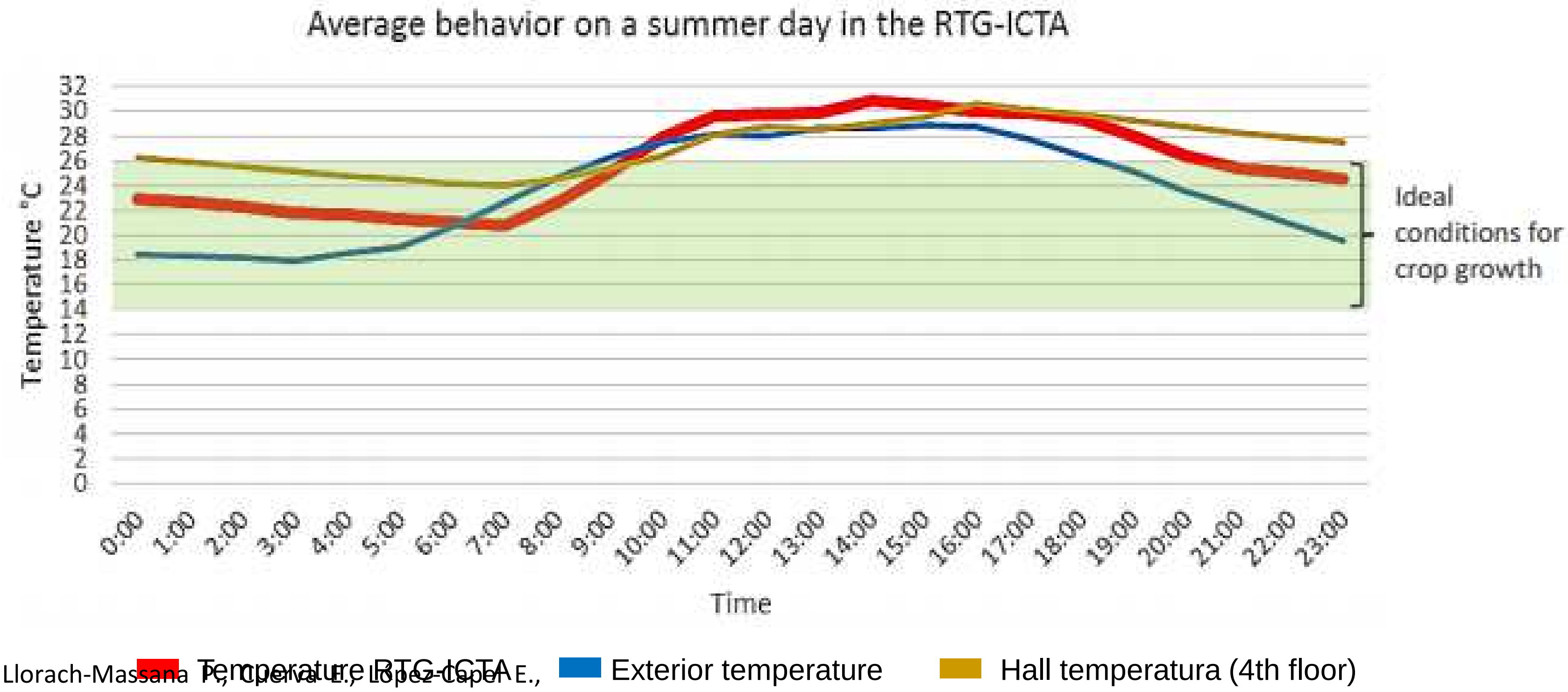
This fact is particularly interesting for greenhouse production during nights, since winter nights reach negative temperatures in the study area thereby increasing the death risk of vegetables.

5.2. General results

Results

Energy efficiency of buildings metabolism for local food production

Summer: average day



Nadal A., Llorach-Massana P., Cuerva E., López-Capel E., Montero J.I., Josa A., Rieradevall J., Royapoor M. **"Building-integrated rooftop greenhouses: An energy and environmental assessment in the mediterranean context".** *Applied Energy*. 2017, vol. 187, p. 338–351. http://dx.doi.org/10.1016/j.apenergy.2016.11.051

The RTG-ICTA night temperatures differ an average of 5° C compared to summer temperatures recorded outside the building.

But during the day the RTG-ICTA presents overheating due to transfers heat of building and due to the materials of the roof and floor.

5.2. General results

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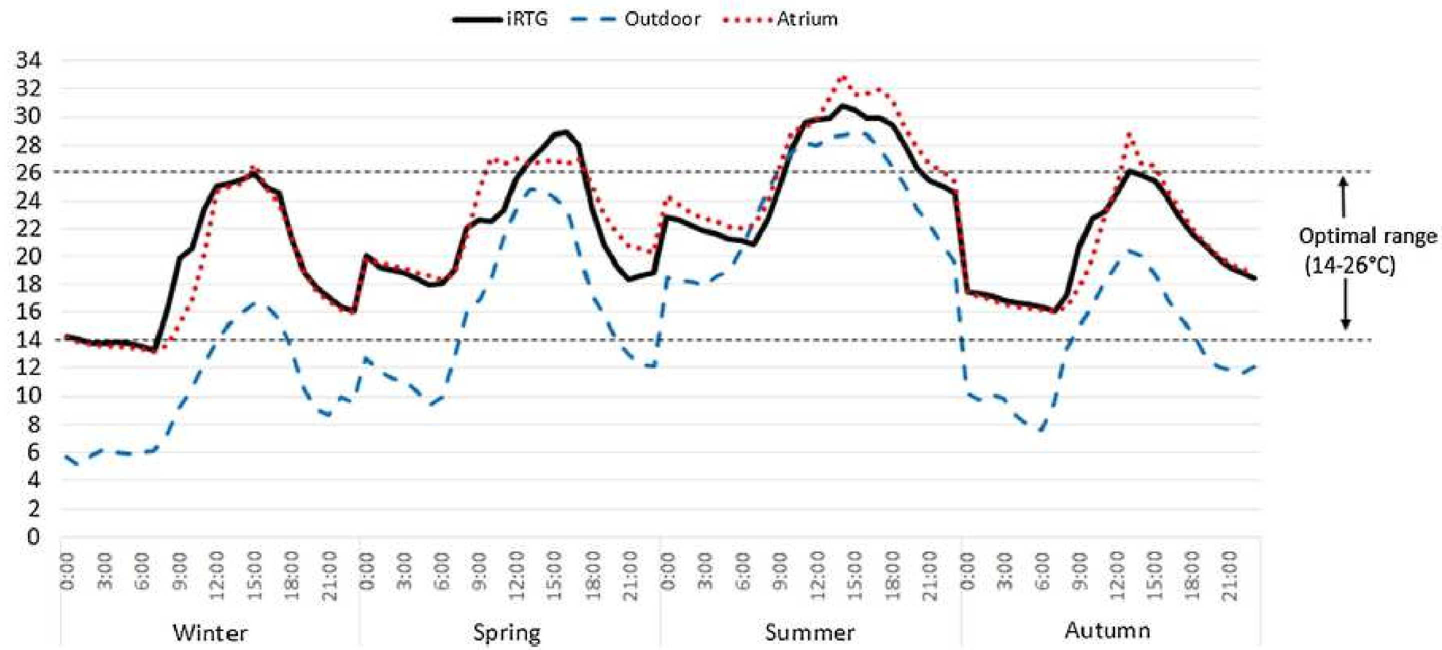

Fig. 5. Averaged hourly 2015 temperatures of 3 probe stations positioned inside the iRTG, the atrium and externally.

Nadal A., Llorach-Massana P., Cuerva E., López-Capel E., Montero J.I., Josa A., Rieradevall J., Royapoor M. **"Building-integrated rooftop greenhouses: An energy and environmental assessment in the mediterranean context".** *Applied Energy*. 2017, vol. 187, p. 338–351. http://dx.doi.org/10.1016/j.apenergy.2016.11.051

5.2. General results

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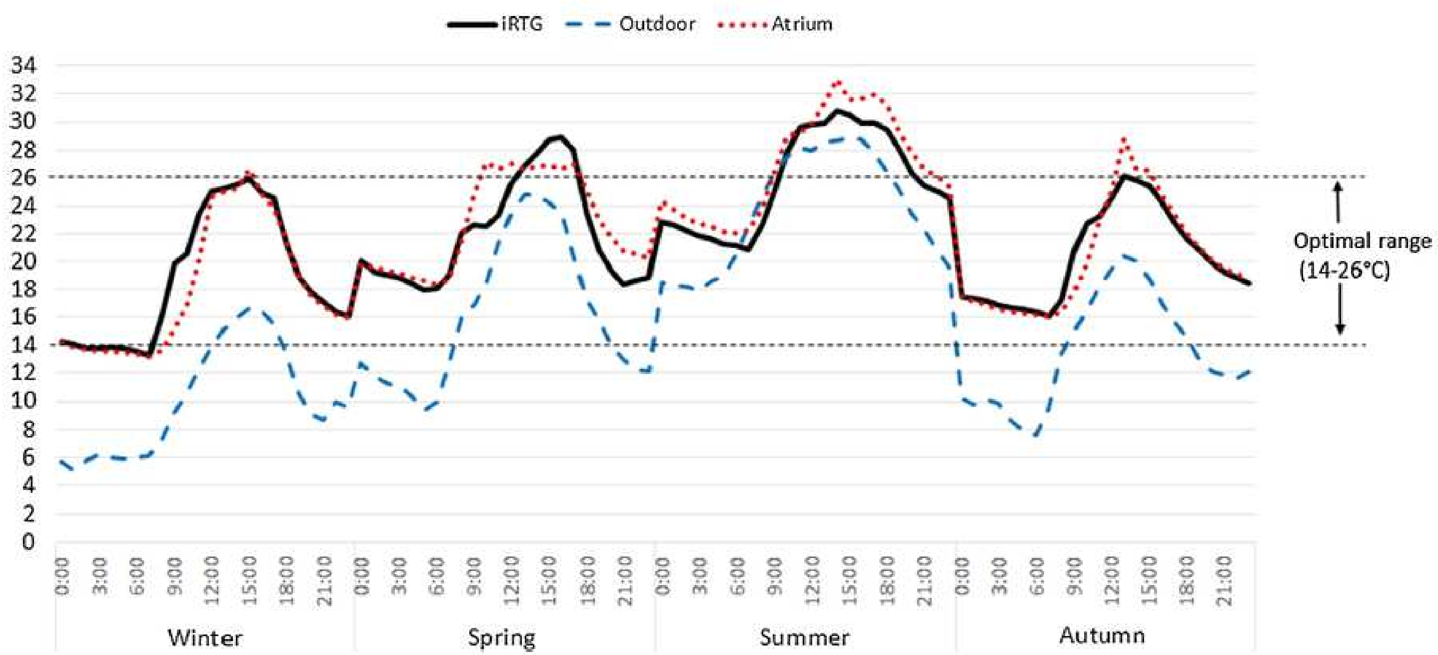

Fig. 5. Averaged hourly 2015 temperatures of 3 probe stations positioned inside the iRTG, the atrium and externally.

- Average temperature of the iRTG varies from **16.5ºC** (winter) to **25.79ºC** (summer).
- In 2015, ICTA-iRTG had ideal temperature conditions for grow in over **76.3%** of annual hours.

- Energy savings of **387.84 kWh/m²/yr** compared to a conventional greenhouse.
- Emissions avoided:
  Diesel: 127.05 KgCO2(eq)/m2/yr
  Gas:93.44 kgCO2(eq)/m2/yr
  Biomass: 7 kgCO2(eq)/m2/yr

ICTA-iRTG demonstrated to be an ideal closed system greenhouse facility for Mediterranean areas.

Future research:

- Characterisation of bidirectional energy performance

5.3. General results

CO_2

LCI of annual CO_2 injected through the residual air of the building

	Total injected (kg CO_2)	**Total fixed by crop** (kg CO_2)	**Ratio** (fixed/injected) (%)
CO_2 flows	42	155.7	30%

- **Human respiration** provides low quantities of CO_2 to the crop
- Potential to **collect more CO_2** from other spaces
- Potential to install additional **CO_2 enrichment systems**

6. Conclusions

Potential saving from i-RTGS

Total $CO_{2\ eq}$ reduction

99,8 kg CO_2 eq. /m^2· year

Total economic benefits

23,15 €/m^2· year

- **Energy advantages** detected provide **99% of CO_2 saving** and **85% of economic benefits**
- **100% of water used could be provided** from the rainwater harvesting system if the irrigation of **ornamental plants** from the building was reduced.
- **Further research** is required to study:
  - The potential to **export daily waste heat from the i-RTG to the cooler zones** of the bottom of the building
  - Analyze the viability of using crop **leachates for building purposes**

7. Acknowledgements

Thanks' to the **Spanish Ministry of Economy and Competitiveness** for founding the **Fertilecity** project

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Thanks' to the **Catalan and Spanish Governments** for the **personal grants** to **Mireia Ercilla, Susana Toboso; Alejandra Peña**

Generalitat de Catalunya

GOBIERNO DE ESPAÑA MINISTERIO DE EDUCACIÓN, CULTURA Y DEPORTE

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