GROOF
Greenhouses to Reduce CO₂ on rooFs

Interreg North-West Europe GROOF

Groof

Guidelines for the installation of rooftop greenhouses

The GROOF InterReg project

This document focuses only on the guidelines, which are a summary of GROOF's experience in designing and building an energy efficient rooftop greenhouse; they contain feedback from existing projects and advice for each phase of the project development, *Maeva SABRE (CSTB, Fr) – 2022*

You want to know more about the GROOF project?

Check our website

Check our guideline

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OUR GUIDELINES

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TO LEAD YOU THROUGH THE DESIGN AND CONSTRUCTION PROCESS

Designed to focus on your project's carbon footprint

By Maeva Sabre (CSTB, Fr), Nicolas Zita (CDEC, LU), Patrice Clément (CEC, BE), Sibylle Cavalier (CEC, BE)

Over time and with the evolution of ecological awareness, economic sectors are influenced by European recommendations to take responsibility for sustainable development. Agriculture and construction are no exception. However, the inertia inherent in these major sectors does not always allow them to keep pace with the changing needs of the market. The GROOF project was born of cooperation between these two sectors and adopts a cross-cutting vision to meet the growing need of a population in search of fresh and local food with eventually a regenerative (carbon positive) footprint, a fresh & local food but also benefits to host building.

Urban agriculture as it is currently perceived is a first response, but it remains today a “niche” trend. To address this problem and develop the European market, the GROOF project brings together specialists from the North-West region of Europe and recognized for their skills in construction, climate, energy & environment management, horticultural production, and commercial development. They are all convinced of the success of an inter sectoral and transnational CO_2 reduction solution involving energy sharing between rooftop greenhouses (RTG) and buildings.

Thanks to its knowledge of the NWE region, the partnership has identified risks and opportunities for early adopters of rooftop greenhouses with CO_2 reduction purpose. The project has also allowed testing several business models on rooftop greenhouse pilots in France, Belgium, Germany, and Luxembourg.

The cooperation also addresses the major issue of CO_2 emitted by long range transportation of greenhouses products. Rooftop greenhouses must act as food hubs and work with local food producers to optimise transport to customers.

Finally, GROOF addresses the territorial challenges of NWE as a heavily urbanised region. Space is scarce and land expensive, especially in urban centres, where the additional need for CO_2 saving measures, local food & greenery is the highest. Rooftop greenhouses are at the same time productive and space-efficient solutions, responding to the inefficient or wasteful existing building stock in NWE.

The purpose of these guidelines is to help rooftop greenhouses (RTG) project owners to introduce energy, construction, and production synergies with the host building in their business model in order to strengthen its robustness while reducing CO_2 emissions.

Existing buildings that do not comply with current thermal regulations can lose up to 30% of stored heat on average through their roof in winter. In addition, heat and CO_2 can be collected through the ventilation systems. The quantity depends on the building’s activities and usage but also on the technical specifications of the installed systems. Each building is different (in size, use, location, materials, energy equipment configuration, bearing capacity, etc.). Because of that, each situation is different and has to be treated accordingly.

However, those specificities do not necessarily imply the use of expensive technical innovations to connect the greenhouse to the building. Any greenhouse manufacturer should be able to build and implement RTGs aimed at reducing CO_2 emissions.

The present innovation lies in the combined work of the construction and agriculture sectors in the design and construction stages to connect the greenhouse to the building in an efficient and cost-effective manner, and also in terms of its management and operation. A successful collaboration will result in a project that will consume less energy than the two structures managed separately.

These guidelines are designed to answer the needs of 4 major stakeholders who will use them in practice: building owners, financial partners, farmers, and project partners.

Are you motivated by the idea of growing vegetables and plants and distributing them locally?

Are you an expert in one of the skills required by the project but maybe not in all of them?

Are you wondering how to start such a project, the steps to undertake, the priorities, and how to optimise them?

Our team of experts carried out numerous observations (visits to existing RTGs, meetings of project stakeholders, etc.), and actually tested four pilot projects in the exclusive property of GROOF. They also coached to 10 others 'early adopters' projects, 5 of which were followed more in depth. Based on this experience and collected data, we organised this document according to the success factors identified for RTG projects with a reduced carbon impact.

This website is structured in six sections:

- Preparation phase of the project
- Execution phase
- Exploitation phase
- Feedbacks
- Pilot projects
- Frequently asked questions (FAQ)

Depending on your profile, you may be an expert in one (or more) of the covered topics and not be an expert in others. In any case, we hope that these guidelines will bring you answers and bring you closer to the success expected for your project. You will find additional reference files for each chapter for you to go deeper into a specific subject.

PREPARATION

COMMUNICATION

By Caroline Bini (Groupe One, BE), Mathilde Gougeau (Groupe One, BE)

This chapter does not deal with 'operational' communication with building companies or suppliers during the construction of Rooftop Greenhouse (RTG) buildings, but with external communication to reach your customers and include them in your RTG project. The present summary is mainly based on the GROOF project experience with the first 4 pilots RTGs and the shared experience of the 10 early adopters.

A communication strategy requires thinking about the meaning and the goals of the project, its contents, but also whom it is intended for and how it will be developed. In other words, which communication tools you will develop to reach your target audience and maximise the success of your building and your RTG, what kind of events you will organise for better visibility and networking around your project, which communication channel you will use, etc.

The goal of a communication strategy is to make project managers ask themselves the right questions, namely :

Make your message more coherent and understandable.

Reach your target audiences (politicians, citizens, urban farmers, partners, customers, etc.), have an impact on them, make them follow your project and include them in your communication strategy.

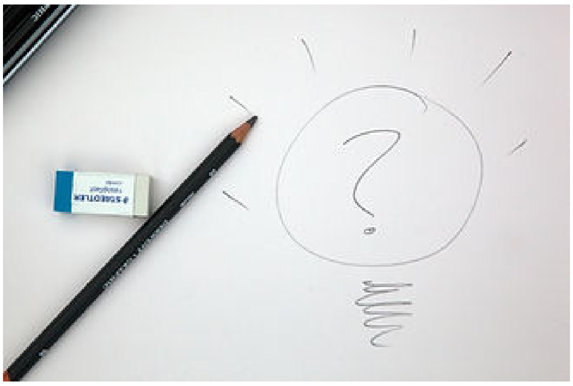
Increase the visibility of your project through specific online and offline strategies.

If you spend the time necessary to prepare your strategy upfront, you will be ready once your RTG is built and when the time comes for you to implement the communication strategy.

DEFINE YOUR MESSAGE! WHY & WHAT

Why does my project exist ?

After defining the roots and reasons of your RTG project in the previous chapter (project outline and strategy), you should have a better idea of what the “raison d’être” of your project is. The outline will answer the question of knowing “why” the project exists. What are the main objectives of your project ? Knowing about your objectives, you will be able to inspire other people : what do people need to feel inspired, join your strategy and get involved in your project ?



It is important that your communication strategy make the link with the purpose of your project because the messages and the way you express them will have to highlight the strongest added value of your RTG for each of the various target groups.

See this video of Simon Sinek that explains the importance of the answer to the question ‘Why’.

What is/are my message(s) ?

Make your message clear enough to make it easy to spread to others! To answer the question “What”, define the project in 3-4 lines and answer the following questions : What are the key messages of my project ? What does the target audience think before communicating ? What do I want them to think after communicating ?

A good message is :

- Clear, simply worded and jargon-free
- With a positive twist and containing a “promise”
- Original, challenging, evocative for the target audience

For example, if you want to develop a non-profit RTG project and focus on social aspects and the production of local food, the two big points of attention in your communication and your message will be :

- Insist on the freshness, local and high quality of your products
- Your project is a point of convergence around food production, but also of events, workshops, and various activities.

You could find a motto such as : Together, let’s gather and produce local food on our roofs!

Tools to develop your message

Storytelling

We invite you to consider your RTG project as a STORYTELLING; what can I say about my pilot project that will attract my audience, what is the background of my project, who are the people involved, what are the values supported by our project ? Feel free to personalise your story and make it accessible, fun and attractive!

Example of one of the projects coached by Groof in 2019

Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis

Based on these strategic elements, we suggest that a SWOT-ANALYSIS of your project could be made so that the strongest elements to be communicated on can be highlighted. The swot analysis will also point out the topics that can be perceived as obstacles or weaknesses by the project stakeholders. It is important to use the strengths in your messages and to set up plans to make the most of these opportunities.

More info in this online video

DEFINE YOUR AUDIENCE

Identify target groups

Once you have answered your message(s) and defined the purpose of your project, it is important to focus on your audience and segment it in different target groups. Who does your audience include ? In other words, answer the two following questions :

Who do you need to communicate with ?

- Inside your organisation : colleagues, head of communication, graphic designer, social media manager, project manager, urban farmers, etc.
- Define who in your team is working on communication and events : is there a dedicated person or team ? Are they available ? Or is the project leader himself/herself working on it ?

Who do you need to include in your strategy ?

- Outside your organisation : influential partners for your audience and in your neighbourhood, citizens, stakeholders, local retailers, etc.
- Define who you need to convince. Who do you need to involve in your project ?
- Typical target groups that we met when we set up the pilot projects included the building owner, building occupants (inhabitants or users), the press, municipal authorities, future customers, financial partners, people living in the vicinity of the building, potential future partners (farmer, grower, supplier, delivery company, etc.).
- See Chapter on social aspects, including stakeholder mapping, to create awareness or empathy among stakeholders, raise awareness, manage expectations, and have an effective dialogue with them to ensure that people support the rooftop greenhouse (RTG).

Observe your target groups

Observe your targeted audience and analyse their needs, their hobbies, interests, geographical location, actions, online behaviours, etc. The better you will get to know them, the more you will be able to meet their needs and you will know how to reach out to them.

Practical exercise

Define a typical persona as precisely as possible and describe a customer success journey!

- Choose a key person
- Describe them, their habits, their needs, their values, where they live, their personal life, their interests, their profession, etc.
- Tell us the story of this persona with your pilot project : how you will reach him/her, how you will interact and raise awareness on RTGs, etc.
- Include your communication tools to reach this person (see the chapter "Define the communication channels") : how will they get to know about your project and get involved in it ? In which field will they be active – on social media, in the street, in online searches, through word of mouth, mailing, events, etc.

Here is a short exercise in .pdf format to practice.

https://www.urbanfarming-greenhouse.eu/_files/ugd/4af052_97801c7170ef4f34bb-61975cd1db122d.pdf

DEFINE YOUR COMMUNICATION CHANNELS

Once the target groups have been identified, it is useful to specify the best communication channels to reach them depending on their needs and behaviour. Where do they get their information from ? Which channel do they use and when ? Are they more receptive to visual/written/direct social contact ?

Your existing communication channels

List the current communication channels that you own : website, e-mail account, newsletters, brochures, advertisements, etc.

Communication channels to be developed

List the channels and promotional tools that you would like to develop to reach your target groups :

- Media coverage to reach the local, national, or international press through press releases, articles, storytelling, municipal magazines, local radios, TV, written press, etc. Is it necessary to organise a press conference, individual visits, and interviews with journalists ?
- Digital communication :
  - Social media (Instagram, Twitter, You Tube, LinkedIn, etc.) : which platform will make sense for my project ? Who can work on it ? Do you have enough content to manage a consistent communication campaign ?
  - New website on your RTG project including articles and news, partners' websites
  - Promotional videos to create the buzz around your project
  - Newsletters
  - etc.
- Print promotional tools : roll-ups, posters, flyers with a common visual identity (colours, images, logo)
- Direct social contact :
  - Development of the right partnerships with organisations that could spread your information
  - Visibility from the street (construction sign and others)
  - Word of mouth
  - Specific targeted phone calls to promote your pilot project
  - Informal meetings and exchanges with friends, the community, neighbours, etc.

By increasing the variety of channels, you increase your chances of reaching the right audience and easily convince them about your message and credibility.

Finally, you can plan the pace of your actions on these communication channels; how often will you post on social media, when will you post which content/article ?

Adapt your message to your target group and your communication channel; what is the strongest message for each group and channel, how can you make your message stand out, make it more fun, sustainable, insightful, original for the purpose of your RTG project.

DEFINE YOUR COMMUNICATION ACTION PLAN

Your budget and human resources

Define your budget for the organisation of events and communication actions : who will oversee the communication campaign and how many people will be involved in the communication strategy ? Do you have a budget for internal human resources, or will you have to externalise for specific skills (video production, graphic design, event planning, etc.) ?

Get people involved in your strategy

Organise a brainstorming with your team and define an action plan that will include your events and your communication actions in a schedule sent to your target groups and communication channels.

Here are a few examples of communication actions for your communication channels :

- Articles and latest news about updates on your project in an article, achieved technical aspects, what I found out through the construction of my greenhouse, etc.
- Press releases to announce the opening ceremony and end of the construction in the press, press conference, etc.
- Newsletter for monthly news, special news on an event or topic, etc.
- Posts on social media : new images and photos of people working on the greenhouse, first vegetable production, photos of events/ workshops/ visits, promotional videos, interviews of the project leader, etc.

Drive other people into action by creating calls for actions : join us, visit our website, discover our project through our workshop, follow us on our social media, etc.

Examples of events targeting specific groups :

- Opening ceremony for a large audience
- Open day for a target audience (municipalities, local population, partners, urban farmers, etc.)
- Study visit : technical visit on a specific topic (construction permit, market gardening, urban farming, energy saving, biodiversity, etc.) with a specific target audience (researchers, farmers, municipal administrators, local population, etc.)
- Specific workshops for anyone interested in greenhouses (researchers, entrepreneurs, etc.) / Educational workshops, teaching and training events for schools, students, architects, etc.
- Conferences, seminars and roundtables, music, and cultural events
- Existing local events to present the pilot project, co-event with a local partner (association, university, firm, etc.)

Schedule your communication action plan

Once you have prepared your events and your material, advertise it on your chosen communication channels at the specific pace decided upfront in your schedule, but keep it flexible to adapt your strategy to the context, novelties, and changes.

Download a communication action plan in .xlsx format

		2021			
	TO WHOM? (Target groups & stakeholders)	Jan.	Feb.	Mar.	...
	Exemples of audience: actors of the territory, research sector, public actors, politicians, construction companies, urban farmers, local population (customers buying vegetables, local residents, etc.), associations, local and provincial media?				
CONSTRUCTION PLANNING					
Permit received					
End of the greenhouse construction					
Production					
EVENTS					
Opening Ceremony	All				
Open Door Policy/Study visit 2	Citizens and the municipality				
Open Door on vegetable production	Urban farmers				
Study visit on a technical topic	Researchers, farmers, investors				
Specific workshops	Anyone interested by greenhouses (researchers, entrepreneurs, etc.).				
Educational workshops, teaching and training Events	Schools, universities, etc.				
Conferences	Researchers, farmers, entrepreneurs, etc.				
Seminars	Researchers, farmers, entrepreneurs, etc.				
Music Event	Local population				
Join local events	Local population				
PROMOTIONAL TOOLS					
Page on the website					
Social medias : Linked In, Twitter, Instagram, You tube					
Video/Drone					
Press: press release, interview (storytelling), articles, etc.					
Newsletter, mailing					
Print material: construction sign, poster, flyer of the pilot, roll-up, etc. (include the dissemination)					

GENERAL ADVICE REGARDING COMMUNICATION

An inclusive and collaborative perspective!

Communication conveys your message : it should include your whole team, experts (to make the message understandable and more credible), the legal representative, HR & employees, other organisations that could help and join your project, etc. Use a well-structured collaborative internet workspace (e.g. Basecamp, Trello, Swello) for sharing documents, ideas, info, etc.

Develop an attractive visual identity

- Find a name for your RTG project that is easy to remember and to link to your message
- Develop a visual identity through a customised graphic charter (logo, colours, typography, etc.)
- Feel free to be creative and original in your communication, give a soul to your project by making it different and closer to your audience

How to deal with a communication crisis

The key to anticipate a crisis communication strategy is to build up a scenario with your team and answer these questions : what are the potential hurdles for firms, customers, and employees ? Remain transparent to keep your audience confident. What can you reveal ? Who are the best spokespeople on this issue ? How can you address the issue to do things properly ? When and how often should you communicate about that ? Which channel will be the most effective ?

Measure the impact of your strategy

How can you make sure that the message will be properly disseminated and will have an impact on the target audience ? Track the behaviour of your target audience through online analyses, event visits, etc. Analyse the key performance indicators of your various channels and target audiences (segmentation) : social media (shares, likes, clicks, views), website (visits, time spent per page, traffic), newsletter (subscriptions, clicks), etc.

PREPARATION

SOCIAL ASPECTS

By Susana Toboso (UAB, Es), Xavier Gabarrell (UAB, Es), Gara Villalba (UAB, Es), Cristina Madrid (UAB, Es), Ramiro Gonzalez (UAB, Es), Caroline BINI (Groupe One, BE)

INTRODUCTION

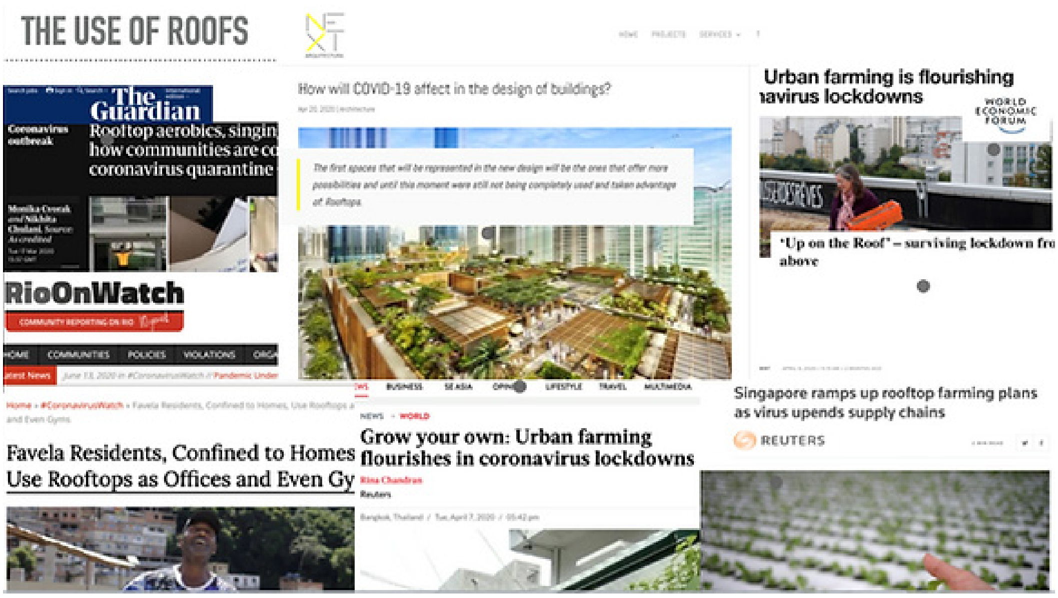
This chapter is an introduction to social aspects generated by a Rooftop Greenhouse project (RTG). Those aspects are influencing your project differently depending on its development phase, therefore this chapter has been divided in several parts and integrated in the respective development phases. https ://www.urbanfarming-greenhouse.eu/

The methodology to analyse your RTG from a social point of view will outline the elements to be considered for a social analysis and provide a step-by-step methodology for different types of RTG implementations.

GENERAL FRAMEWORK

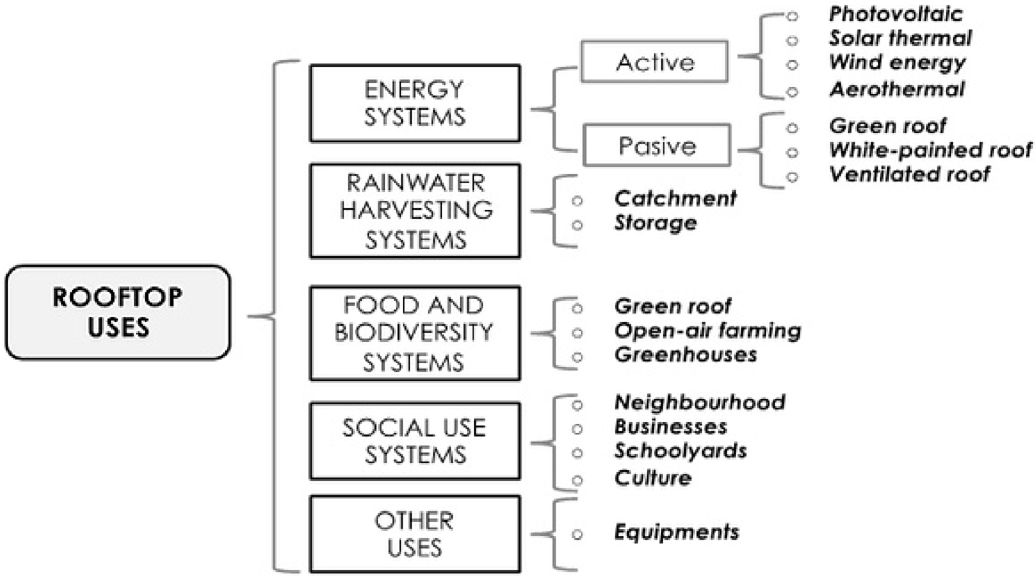
Urban agriculture is normally associated with crops at the ground level and is appreciated for its benefits to the community. It is mainly perceived as a socially oriented activity, including recreational and leisure projects that are highly valued by citizens. However, profit urban farming initiatives are less accepted, since food security is not currently perceived as a problem in most European cities (however, this point is changing faster due to the COVID19 pandemic (see figure bellow), and it relies on a recreational goal that is currently prioritised over a commercial vision. Among consumers, products from urban farming are expected to be fresher and of a better quality because they are harvested just before consumption. Consumers prefer urban farming products to conventional rural products if they meet specific criteria : high quality, regionality, organic production, or the inclusion of additional social benefits.

Figure : news about the use of the rooftops in Covid-19 lockdowns.



Different considerations have to be examined when a novel project is implemented. Rooftop Greenhouses (RTGs) are quite a new system in cities (see different systems deployable on roofs in the figure bellow), and the social aspect should be considered too. Different studies have analysed the social acceptance of these projects among stakeholders using different quantitative and qualitative methods (Sanyé-Mengual et al., 2016; Specht et al., 2016; Specht and Sanyé-Mengual, 2017). Other studies have examined the barriers and opportunities of their implementation on urban roofs (Zambrano et al., 2020; Cerón-Palma et al., 2012), and concluded that barriers related to agreement among neighbours and organisational issues still remained to be overcome.

Figure : list of possible applications on rooftops



We propose a bi-directional reflection at the beginning of the project. The first one is the consumption pattern of the people living in the urban area where the RTG is proposed, which can vary considerably depending on the employment status, age group, or type of family structure (Toboso-Chavero et al., 2020). A survey about consumption patterns is an option to be considered before developing the project (See the results of a survey conducted by the Autonomous University of Barcelona and a study conducted for the FertileCity project). The second reflection is focused on the residents' opinions for a successful implementation of the RTG. Many studies advocate in favour of different forms of participation of the general public and stakeholders in decision-making when their daily life is concerned (Bidwell, 2016; Walker and Devine-Wright, 2008). Different opinions are important and collecting their diversity can help to overcome possible issues. This can be done using participatory processes or questionnaires.

GENERAL PURPOSE

The general purpose is to recommend a methodology to carry out a social analysis in this type of novel project, aimed at their social acceptance and long-term success.

PREPARATION

COMMUNICATION TIP

By Caroline Bini (Groupe One, BE), Mathilde Gougeau (Groupe One, BE)

At this stage of the development of your project, it is essential that you focus on your communication strategy by developing your concept and idea in order to get your future consumers and stakeholders involved. The project leader will particularly focus on the definition of the main message, the "why" of the project, and anticipate the behaviour of the target audience as well as of the stakeholders, as explained above. More details in Communication chapter.

For instance, the goal of your rooftop greenhouse (RTG) is to show that there exist alternatives to reduce CO_2 emissions. To achieve this goal, you will plan to organise awareness campaigns, workshops, and visits with construction students and future urban farmers, but also to do active lobbying with local municipalities. Your main target audience will be the students and workers from the construction and farming sectors, as well as politician.

PREPARATION

PROJECT OUTLINE AND STRATEGY

By Nicolas BRULARD (Fermes de Gally, FR), Nicolas Ancion (ULg, BE)

You are :

- A roof owner
- An architect, an engineering office
- A private or public funder
- An urban farmer – producer

You are wondering how to set up an rooftop greenhouse (RTG), with whom, why, how to fund/operate/sustain it. So many questions that you can (and should) rightfully ask yourself.

Based on our experience, here are 4 diagrams that bring together the steps involved in the good conduct of your project, according to your role in the project and your skill profile.

How can I go further ? Browsing the guidelines will allow you to go deeper into the various points covered in these diagrams.

Building an RTG is a long-term commitment. Unlike land-based agricultural greenhouses, RTGs combine the challenges of the construction, energy, and horticulture industries. If you want to benefit from the synergies between the greenhouse and the building (energy savings, water recovery, consistency of uses, well thought out access and logistics), you will need to coordinate your project with the building stakeholders and coordinate your agendas more than ever for multi-year projects.

We produced a factsheet for each type of stakeholder to help you carry out your RTG project. These sheets are a dynamic table of contents to help you read the GROOF guidelines depending on the progress of your project. These stages of the project are based on experience from the four pilots GROOF greenhouses and on the feedback from the projects supported by the GROOF partners. In the digital version of the guidelines, you can click on each step to access the corresponding sheet in the guidelines.

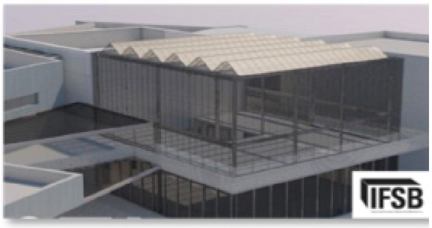
HOW TO PILOT YOUR GREENHOUSE ON ROOFTOPS ?

Project steps and overall plan of GROOF resources

Urban rooftop greenhouse (RTG) projects are often complex because they involve many stakeholders from the agriculture, construction, energy sectors, and from the city. They all have their own vocabulary, project timing, objectives, and constraints. These projects generally take 2 to 5 years depending on the context; you will have to stay on course and be motivated over time!

As part of the Interreg NWE (North-West Europe) Greenhouses for CO_2 Reduction on Roofs (GROOF) project, here is a project management framework for each stakeholder, with 2 objectives :

- Provide a framework for managing your project, from the initial idea to operation,
- Facilitate your access to the various Groof resource sheets on production, business plan, climate management, and links with the building.



Roof owners

My stakes

I want to add value to my roof and enhance the energy efficiency of my building with farming, but I do not know how to do it.

I want to develop new uses for my roof and around my building, around the topic of urban agriculture and sustainable buildings.

I would like to reduce the carbon footprint of my building.

The building is a new building or an old building, with or without a rehabilitation program.

Motivation, first interest

Why should I integrate urban farming in the project?
- Motives: why a greenhouse?
- Greenhouse/building CO_2 and energy synergies

General information about greenhouse projects
- Estimated investment, deadlines
- Check-list of success and failure indicators

Does the building fit with an RTG project?
- Minimum specificities required for the project
- Check-list of key data (with/without CO_2 recovery)

Why this project for the owner ? Which interest for him/her?
Why urban farming rather than photovoltaic power production or other energy devices?
Why a greenhouse rather than urban farming without a greenhouse? Or a combination?
Why not on the ground?
Why combine energy and building rather than two distinct approaches in this context? Which timing for these two topics?

GO - NO GO

Tech-eco feasibility

WHICH TEAM FOR THE PROJECT
How to set up a team? With who?

Which key stakeholders? In particular which farmer?
Which are the farming alternatives?
Which “market” for greenhouse renting?

- Which actors and local structures to associate with
- Budget estimations
- Recoverable resources, heat, CO_2, how?
- Which financers to consult? When?
- Regulations, applicable standards
- Roof structure, weight, access: OK or to be adapted?
- Which economic model to favour in my case
- Examples of estimated tech and eco models

GO - NO GO

Project launching

Building up of the project management team ↔
- **Building expert/advisor**
- **Energy expert/advisor**
- **Production and business plan expert/advisor**

Architects, engineering offices

My stakes

My client wants rooftop farming. I need to make the difference between a greenhouse and a veranda in terms of design, flows and climate management.

I am responding to a competitive call, with specifications for an urban greenhouse or urban farming. How can I design a sustainable, technically/economically/thermally efficient project? Climate management, greenhouse specific needs (heat, irrigation, rainwater recovery).

How can I design a viable project over time? Maintenance of the greenhouse structure, plan B in case the greenhouse is no longer operated by the initial farmer, etc.

Motivation, first interest

Why should I integrate urban farming in the project?
- Motives: why a greenhouse?
- Greenhouse/building CO_2 and energy synergies

General information about greenhouse projects
- Estimated investment, deadlines
- Check-list of success and failure indicators

Does the building fit with an RTG project?
- Minimum specificities required for the project
- Check-list of key data (with/without CO_2 recovery)
- Cost estimation
- Structure reinforcements needed?

Why this project for the owner? Which interest for him/her?
Why a greenhouse rather than urban farming without a greenhouse? Or a combination?
Why combine energy and building rather than two distinct approaches in this context? Which timing for these two topics?

BEWARE, A GREENHOUSE IS NOT A SOLARIUM ≠ Climate management

GO - NO GO

Tech-eco feasibility

- Roof structure, weight, access: OK or to be adapted?
- Recoverable resources, heat, CO_2, how?
- Regulations, applicable standards
- Budget estimations
- Examples of estimated tech and eco models
- Which economic model to favour in my case
- Which stakeholders and local structures to associate with
- **Which materials? Is the design suitable for the requested surfaces?**
- Team facilitation
  Team project leadership

GO - NO GO

Project launching

Classical construction stage → **Potential maintenance**

Building up of the project management team ↔
- **Building advisor**
- **Energy advisor**
- **Production and business plan advisor**

Interreg North-West Europe GROOF

GROOF Greenhouses to Reduce CO_2 on rooFs

Public or private financers

My stakes

I am asked to fund an RTG locally because it would be sustainable and innovative. Should I fund it?

How can I improve local regulations to favour or allow RTGs and urban farming?

Take all greenhouse resources into account: social enhancement, production, CO_2 reduction, energy gains.

Motivation, first interest

Why should I integrate urban farming in the project?
- Motives: why a greenhouse?
- Greenhouse/building CO_2 and energy synergies

General information about greenhouse projects
- Estimated investment, deadlines
- Check-list of success and failure indicators

Does the building fit with an RTG project?
- Minimum specificities required for the project
- Check-list of key data (with/without CO_2 recovery)

Overall understanding of the concept
Project understanding: goals, real impact *vs.* socio/eco/environmental impact
Assessment of ecosystem services
How can I measure the viability of the project and its leader? (AMI, AAP, market study)

GO - NO GO

Tech-eco feasibility

Why support/help an RTG project?
Which interest? Which value?

How to help, support:
- **Skills**
- **Subsidies**
- **Subsidised loans**
- **Area, localisation**
- **Political structure**

Which key stakeholders? In particular which farmer?
What are the farming alternatives?
Which "market" for greenhouse renting ?

- Which actors and local structures to associate with
- Examples of estimated tech and eco models

GO - NO GO

Project launching

- Opening ceremony and nice pictures
- Follow-up of the project commitments

Urban farmers - growers

My stakes

I am a farmer and I want to expand my business in the city with an urban farming project or an RTG. How can I build an economic and ecological project (which methodology)?

I am a new urban farmer whose first project is a greenhouse. Is it feasible? How?

How can I measure the benefits that my project will bring locally besides selling products? Social bonds, ecosystem services, etc.

Motivation, first interest

Why should I integrate urban farming in the project?
- Motives: why a greenhouse?
- Greenhouse/building CO_2 and energy synergies

General information about greenhouse projects
- Estimated investment, deadlines
- Check-list of success and failure indicators

Does the building fit with an RTG project?
- Minimum specificities required for the project
- Check-list of key data (with/without CO_2 recovery)

Business model canvas / Why this project: economic project, team, targeted market
- Be careful with innovation! Being innovative does not mean that it will be sustainable
- Be careful with the reality behind exploitation: life project, constraints, holidays, BXL viability indicator, etc.
- Technical project
- Schedule and budget indications

GO - NO GO

Tech-eco feasibility

WHICH TEAM FOR THE PROJECT? Who can support me?

Which are the key actors? Relationships with traditional farming structures: develop a network, shared items, technical references

- Regulations, applicable standards
- Roof structure, weight, access, available heat?

Stay focused despite all the building requirements! (closely related to "WHY"), know when to leave the project or reshuffle it

Keep a plan B in mind if the project takes too long, is too costly or unfeasible, Contract with the owner from the beginning of the project

Funding : who will fund the investment? Who will fund the operation?

GO - NO GO

Project launching

Classical construction stage → **Exploitation**

Building up of the project management team ↔
- **Building advisor**
- **Energy advisor**
- **Production and business plan advisor**

PREPARATION

TECHNICAL FEASIBILITY

By Marcel DERAVET (IFSB, LU), Ismaël BARAUD (CSTB, Fr)

The technical feasibility of a rooftop greenhouse (RTG) project must consider all the usual procedures related to the construction sector and include the criteria related to the innovative nature of this typology/concept.

There is no supporting EU (European Union) guidance or standard regarding the integration of a greenhouse on a rooftop. Therefore, it is necessary to i) develop a technical design file explaining the chosen technical solutions, and ii) provide the justifications to demonstrate :

- The strength and durability of the work
- The feasibility of the construction and maintenance operations
- The safety of users and stakeholders in the construction and operational phases

This technical guide will necessarily involve the various stakeholders of construction for them to describe their work while considering the specificities related to the construction of a greenhouse on a roof.

The purpose of this chapter is to present the points to be addressed to design a project and validate its feasibility.

NEW BUILDINGS

The focus is on evaluating the design project in relation to the building regulations currently applied in the country.

The designer should provide the various stakeholders with the assumptions to be considered when establishing technical feasibility.

Depending on its surface and its total or partial occupation of the roof, the RTG will be adapted to different roofing types :

- multi-use roofs when the greenhouse is located nearby technical areas, areas accessible to pedestrians, inaccessible areas
- greenhouse roofs when the greenhouse occupies the entire roof surface

In many cases, RTGs are located nearby equally innovative areas such as garden roofs, roofs equipped with solar panels, etc. In that case, it is necessary to demonstrate the overall feasibility of the RTG.

Designers assisted by the technical engineering office and structural engineers should justify structure calculations considering the permanent loads and the operation of the greenhouse, resistance to climate conditions (wind, snow) in order to demonstrate the solidity and durability of the structure.

The stakeholders are the building contractors and the greenhouse contractor. The assumptions of their calculations need to be worked on in common.

Designers should justify the choice of materials (insulation, waterproofing, coating) in terms of properties and technical performance to demonstrate the durability of the work. For example, they should justify the choice of a particular thermal insulation material (e.g. when it deviates from current construction rules or current thermal requirements).

Designers should justify where technical equipment should be installed and its connections with the greenhouse (plumbing, electricity, ventilation, etc.).

For example, the location of network crossings, ventilation exits, aeraulic systems, etc. will have to be justified.

EXISTING BUILDINGS

In this case, the focus is on diagnosing the roof and structure of the building to determine whether building a greenhouse on the roof is feasible and to implement the facilities in the building. The original structural calculations or a new structural report are needed.

The greenhouse designer and the renovation contractor will set up a technical file in which the calculation hypotheses have been collected, when they exist; otherwise, a new structural study of the building will have to be performed. This design/renovation file (Structural evaluation/structural report/building manual (UK)) must demonstrate that the building will be preserved, existing structures are solid, non-structural works are compatible with the construction of a greenhouse, and the safety of users and stakeholders will be ensured.

If necessary, the technical file must detail the preparatory work required to strengthen the structure or modify it.

General aspect of the building

- structure, foundations
- number of floors
- accessibility
- localisation relatively to neighbouring buildings

Detailed analysis of the building

- roof composition
- roof layout (ground shape, technical equipment, rainwater outflow, etc.)
- stairs and lifts
- basement or crawl space

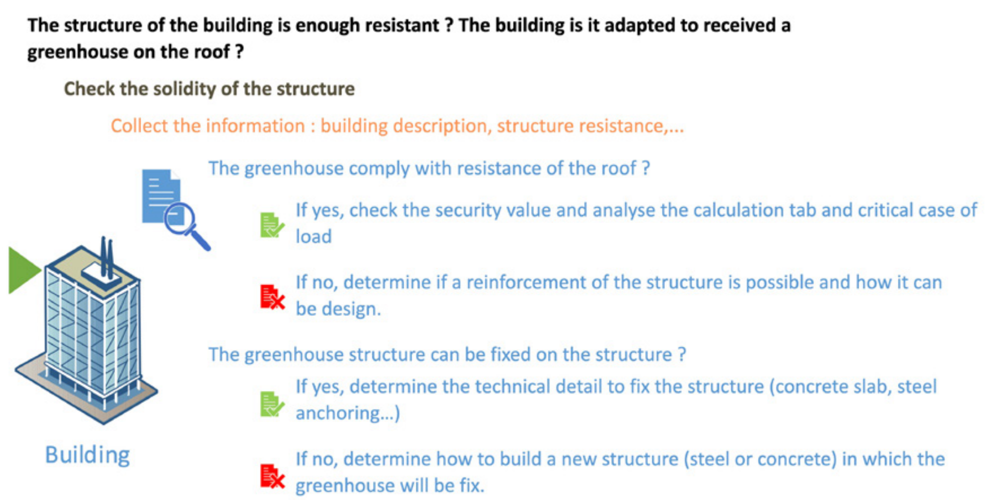
Analysis of the overall aspect of the building

Structure : The primary criterion for determining whether a greenhouse can be built on the roof is the building's load capacity. The best information will come from the calculation note of the engineer who designed the structure, but we can also refer to Eurocode 1. The first analysis focuses on the structure and evidence justifying potential overload.

Description of the structure

- owner must provide the building design teams with the plans, calculation assumptions and criteria taken into account for the construction of the original building
- (structural builders) must provide the archives of the execution work, the beam plan, slabs, braces, service cavities, foundations, etc.
- architect must provide the original architectural files if they still exist

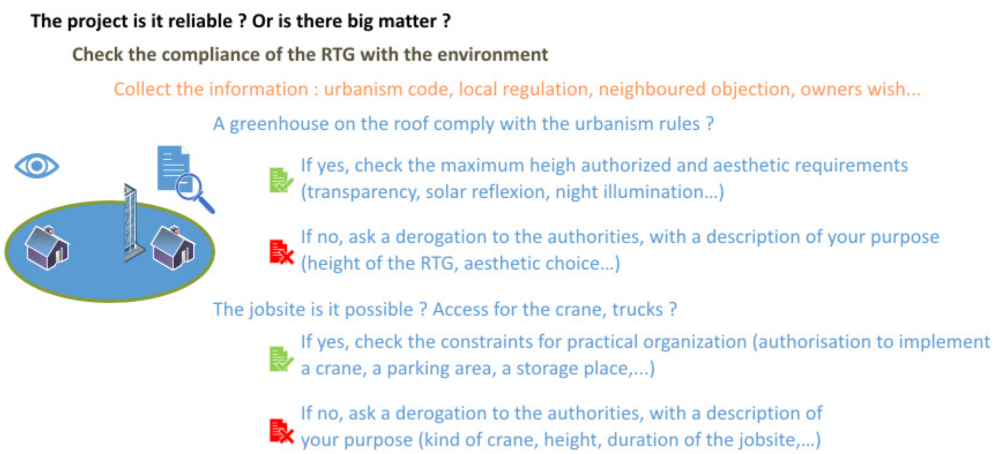
If these data cannot be provided, a structural diagnostic must be carried out by a structural design office in accordance with local regulations. A topographic study and a plan showing the dimensions of the existing building are also necessary.



Number and height of floors

The number of floors is relevant to determine the link between the greenhouse and the building. It is important to take this parameter into account. The floor below the roof should be well described to determine the possibilities of installing greenhouse facilities as close to the greenhouse as possible to reduce the length of the network (pipes, cables, etc.).

The basement floor should also be well described to identify the possibilities of installing a water tank, storing materials for the greenhouse, the primary heat pump...



Accessibility

Accessibility to the roof is really relevant because if access is non-existent or difficult, major work should be done to create access while focusing on safety issues.

Accessibility depends on the number of floors. If the building has only one floor, accessibility may be limited to a simple staircase located indoors or outdoors. The staircase must be wide enough to be able to deliver the material to the greenhouse and ensure user safety.

If the building has several floors, accessibility will be made possible both via a staircase and via a lift to comply with fire safety regulations, to facilitate the movement of workers/visitors and the transport of loads, etc. In addition, dedicated access to the greenhouse may be necessary to take other activities in the building into account (everyday life in a residential building, working in an office building...).

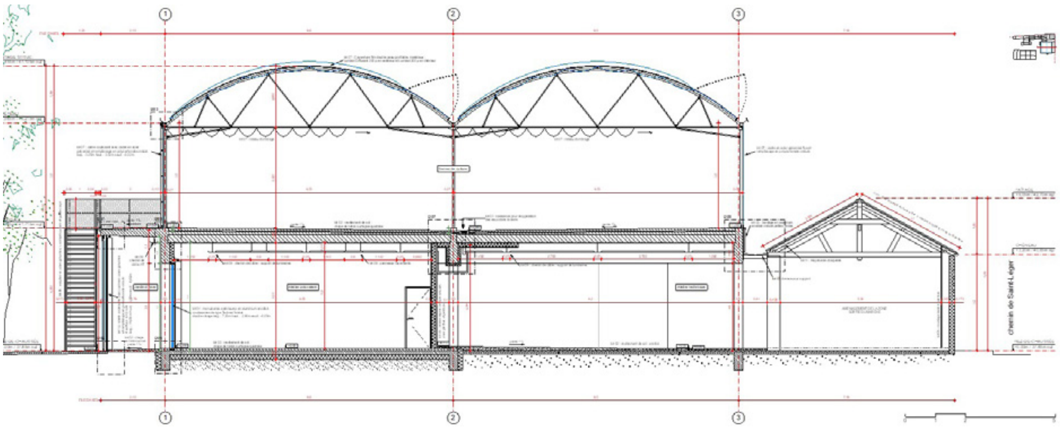
Situation with respect to neighbouring buildings

The design and organisation of the RTG project will greatly differ depending on whether there is an interaction with neighbouring buildings or not. If the greenhouse is in contact with other buildings, this interaction must be evaluated and managed in terms of light, shading, noise, easements paths, etc.

The height of the building will be studied according to local urban planning regulations, modelling can predict the impact of the greenhouse on neighbouring buildings.

Detailed building analysis

Roof composition



The roof composition is directly linked to the energy chosen for the greenhouse project. It can lead to choices of different materials or equipment.

It should be well identified (e.g. a concrete slab, a steel structure, wood). The watertightness /roofing contractor will provide the maintenance contract, the roof layout, and the work record. The type of insulation and waterproofing technique will need to be identified in order to accurately study the load capacity and ensure the feasibility of the work.

Additional work may be needed to protect the roof. For example, adding heavy protection or a new mechanical high-strength sealing layer, suitable for pedestrian-accessible roofing.

Other work may be to be planned or avoided.

For example, when it comes to thermal insulation of the roof :

- If the existing insulation is not mechanically resistant enough, it will have to be replaced. In this case, the designer, assisted by the thermal design office, will have to demonstrate that the choice of a new insulating material exclusively based on mechanical resistance, which often leads to lower thermal performance, is relevant. Therefore, they will have to argue in favour of an insulating material that does not reach regulatory thermal performances.
- Similarly, if the existing thermal insulation is mechanically resistant enough but its thermal performance is low, the designer, assisted by the thermal design office, will have to demonstrate that keeping the existing insulation will be a source of savings (insulation + waterproofing will not be replaced) and that the energy from the greenhouse will participate in the recovery of the thermal loss of the existing roof.
- For more information about insulation, see chapter Exploitation, Managment and farming systems of rooftop greenhouses.

Roof plan (relief, slope, technical equipment, rainwater outlet, etc.)

The owner or watertightness/roofing contractor will provide the full list of roof installations and each maintenance contract (HVAC, antenna lightning rod, etc.).

The watertightness/roofing contractor will provide the layout of rainwater outlets. There may be an opportunity to determine how many rainwater outlets can be shut down and how many need to be kept collecting rainwater running down from the greenhouse cover.

If rainwater is to be collected, the transformation of rainwater inlets and downspouts and their connection to rainwater recovery tanks should be described.

In view of the experience the greenhouse structure must be integral with the building shell structure, therefore work should be done to create reinforced concrete or metal posts to anchor the greenhouse in the structure. Specific studies should be carried out to determine the wind resistance and stability of the greenhouse structure.

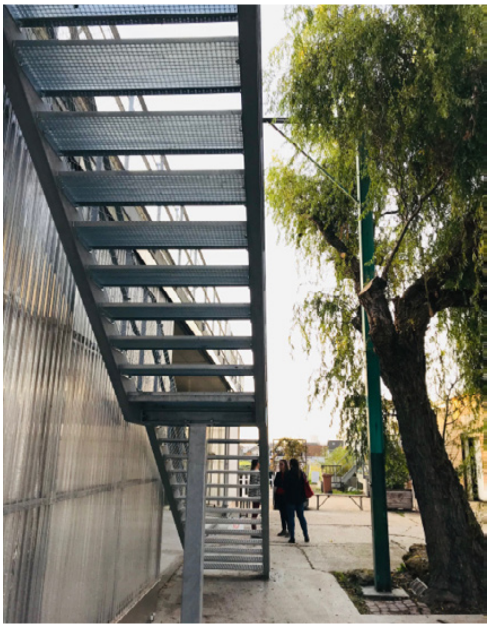
If technical equipment needs to be modified or moved, the transformation work will be described (elevation, displacement, connections, etc.).

If the roof slope needs to be corrected, the work will be described, and the chosen technical solutions will be detailed and justified.

The current trend of the construction market clearly favours the design of buildings with functional and accessible flat roofs. As a result, flat roofs and top floor floorings are increasingly designed to be compatible with pedestrian use. In the wake of this trend, reversing ongoing projects to propose that a greenhouse be installed is indeed possible. Modifications will be less than in the case of an inaccessible roof design. Architects are sensitive to the question of the multi-functionality of roofs and like to combine uses (greenhouses, entertainment area, technical area, etc.).

When existing technical equipment is preserved and is found inside the future greenhouse, it is necessary to determine how it will remain accessible for maintenance and how it will be secured (covering, barriers, etc.) to prevent greenhouse workers from interfering with this equipment.

Stairs and lifts



Stairs and lifts will be analysed and checked for their ability to bear the constraints related to a greenhouse. For example, a lift must have sufficient load capacity for the people and materials required daily for greenhouse activities. The sizing of the lift will also be in line with the number of products harvested in the greenhouse. Stairs will be located near the greenhouse to avoid crossing private spaces under the roof.

Otherwise, the design of new specific accesses (outdoor stairs, new lift sheath, foot bridges) and access paths to the greenhouse will be described from a technical point of view.

Basement

The basement of the building will be accurately described to determine its potential for transformation so that the facilities necessary for greenhouse activities can be installed (the surface area of the room will depend on the size of the greenhouse and the type of crop grown in it).

REFERENCES to go further in the roof design (please refer to your national institutions) :

- Building code and national construction rules
- Standards and Eurocode
- NF DTU (Norme Française Document Technique Unifié) series 43, 20-12 standards for constructions in France
- National technical approval, Technical Assessment of construction processes,
- Building Information Modelling (BIM) digital model

FINANCIAL FEASIBILITY

By Boris SOLEKI (Neobuild, LU), Patrice CLEMENT (CEC, BE)

INTRODUCTION

The purpose of studying the financial feasibility of your project is to determine if – and when – the project revenues will cover the costs and generate a profit. Since you are going to start from scratch, this feasibility study is mainly based on assumptions about costs, investments, and sales volumes.

This will help you determine whether you can expect your project to generate profits and cash or whether it will require additional funds or revenue action plans to reach a financial balance. This section will guide you on how to make and verify your business assumptions and how to integrate the revenue and cash flow forecasts of your project.

You should be able to anticipate problems and take countermeasures to avoid them. All of this is the entrepreneur's responsibility.

This document gives you some basic methods, tips, and a basic calculation tool to estimate the income (P&L : profit & loss) and the cash situation of the project at every moment.

BUSINESS HYPOTHESES

When you outline your project, some data are known, and others have to be estimated. The first important thing to do is to try and make your estimations as accurate and sure as possible. For the investment part, see to it that everything is included in your calculations and double-check by calling for tenders from several potential suppliers (see example below "Cost Calculation Bürstadt"). You will mostly know the costs of the biggest investments (building, land, most important devices and facilities, etc.). As for the revenue forecast, make your market study as accurate as possible, not too optimistic as to sales prices, competitors, customer behaviour, etc. A good way to make reliable estimations is to double-check if each forecast figure of each line of your calculation file is realistic. If you can find state-of-the-art examples or business experiences to base your estimations on, do not hesitate to use them. Besides forecasting the operation of the business with hypotheses that you find realistic, a way to secure the business is to make a worst-case forecast. This means that the P&L and cash forecasts are based on the most pessimistic hypotheses. The idea is that if the business keeps its P&L and cash balance with pessimistic hypotheses, it should be very safe in reality.

INVESTMENTS AND COSTS

	Cash = amount in bank account or in cash.	
Fixed costs	expenses that are always present, independent whether you produce or not	
	Energy (water, electric power, gas etc)	
	Project development costs (architect etc)	
	Permanent employees (staff)	
	Legal (cadastre)	
	Insurance	
	City costs (rubish collection…)	
	Participation in building costs	
	Cleaning offices	
Variable costs	Leasings (building, vehicles, furniture, machines ?)	
	Raw materials product 1	
	Raw materials product 2 etc	
	Tools	
	Consumables (oil, gloves, paper, bags, etc)	
	Packaging	
	Variable employees	Employee 1
		Employee 2
	Taxes	
	Transport	
Cash from sales	Sales Product 1	
	Sales Product 2	
Loans	for each investment the amount you have to pay to your provider or to your bank (bank loan or other creditors)	
	Loan 1	
	Loan 2	
Subsidies	A subsidy is included in the cash when they are paid by the creditor. It can also be released in 1 time or in several times.	
Total Cash	operational result - Depreciation costs + financial result	

In the example 'Construction Cost Calculation' attached, you can find a calculation model for a standard rooftop greenhouse (RTG) construction. The worksheet is intended to be as complete as possible in the case of RTG construction on an existing building. The costs of adaptation of the existing building, roof adaptation, RTG construction and RTG equipment stick to real pilot experience. The structure may have to be extended or completed to follow your specific project. The essential principle is that investments will concern all the purchases that will only have to be made once before you can start your own RTG project. These items will last for several years before they have to be replaced. They will be subject to depreciation corresponding to their life cycle in the RTG bookkeeping.

As for costs, we suggest another 'Budget Estimate' worksheet where you can integrate fixed and variable costs for every working period (mostly 1-year periods). Fixed costs are those that are to be paid regardless of whether you are producing or not, and variable costs are directly related to your production. For example, fire insurance will have to be paid for even if production is stopped (fixed cost), whereas seeds will only have to be bought for production (variable cost). Several software programs are available (like Agritechno); better still, you can work with a consultant.

OPERATIONAL REVENUES

Additional incomes are possible (saved water, recycling or energy production by machines). It is important to mention cash revenue sources that have to cover the cash needs at any time : operational revenues are those from greenhouse products sales + own cash investment + subsidies + bank credits + possibly a cash pool from crowd funding or cooperative investors. The cash situation in the excel file should also contain 1 line per cash revenue source to check that the total available cash covers cash needs at any time.

P&L VS. CASH

When making a business plan, the P&L forecast has to be independent from the cash forecast. At any moment the P&L result is generated by the difference between all the recorded costs and revenues. But the cash situation is the difference between revenues and expenses. The cash balance is the amount of cash that is available in the project at any moment. Every day, it is the money you need to spend vs. the money you receive from your customers and other cash sources. For example, if you buy a product for 10 € and sell it for 12 €, you will book a cost of 10 € and a turnover of 12 €, so the P&L bottom line will be a profit of 2 €. But if you already paid the invoice of 10 € to your supplier and your customer did not pay the invoice of 12 € to you (e.g. because you allowed him/her to pay 1 month later), your cash situation at this same moment will be - 10 €. Therefore, both a P&L forecast AND a cash forecast need to be made. Bankruptcy never happens because of P&L, but because of negative cash situations.

LEGAL ASPECTS

Taxation systems and the way businesses can manage their costs, expenses, and revenues greatly vary among countries. Good examples are the way the depreciation of an investment is considered or labour cost taxation levels, which can differ a lot across Europe. So always check the accounting rules and taxation system applied in the country where the investment is made, especially if your plan to invest abroad.

FORECAST PERIODS

A forecast can be made per month, per trimester, semester, per year or even daily. Our advice is to forecast P&L and cash using "the higher the financial risk, the shorter the forecast period" as a principle. In most cases the bankruptcy risk is high at the beginning because high expenses need to be made although revenues are close to 0. This means that it is safe to control the cash situation very frequently to avoid default payment which can block the business. After the first months/years of experience you can revise your forecast based on the calculation of the actual business results. If upcoming periods are 'copies' of actually experienced periods, the risk will be lower, and your forecast will be more reliable and accurate. Then you will be able make new forecasts over longer periods.

KEY PERFORMANCE INDICATORS (KPIS)

To keep an eye on the health of the business, key performance indicators (KPIs) can be defined and measured regularly and compared with the forecast to see if the business is running above, below, or equal to expectations. Like driving a car, each KPI tells you if the car drives as it should be. Like speed, oil, petrol for a car, each crucial datum of the business is measured to tell you if the business is healthy or if something needs to be adapted. KPIs altogether form the dashboard of the business. This allows the manager to take relevant decisions. So, if most KPIs are above your expectations, you can decide to accelerate the business growth by asking more money from the bank, recruiting one more employee, launching a new activity (product) sooner than planned, etc. On the contrary, if KPIs are not doing well you can decide to stop producing a non-productive product or delay an investment.

Most financial partners like to see the performance of their investment measured. They consider this as a risk reduction factor.

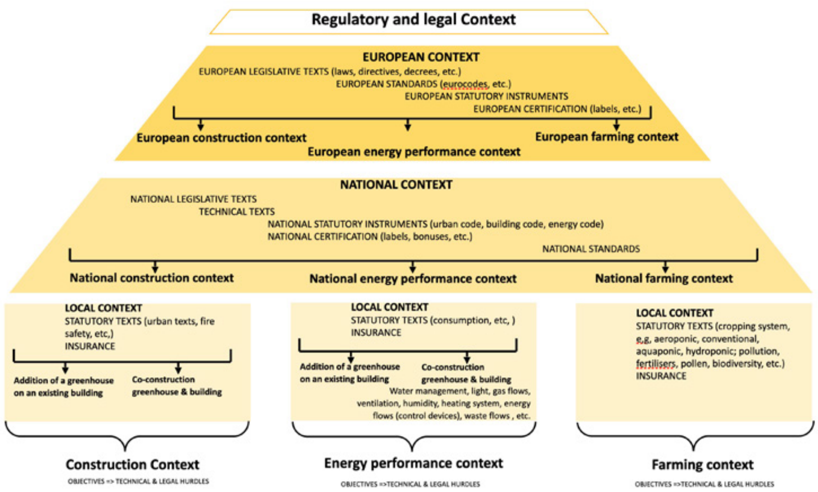
NB : KPIs can be financial but also commercial or operational (e.g. they can measure the actual stock volume vs. the ideal stock volume, sales volume, waste volume, etc.). It is good to measure KPIs for all aspects, which are mostly inter-related. In this specific case, KPIs can also be environmental.

Chapter TECHNICAL, ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF ROOFTOP GREENHOUSES provides more details about KPIs and the way to monitor the RTG from an economic point of view. Some suggestions are given as to which KPIs to follow according to the type of results that are crucial for your RTG.

PREPARATION

LEGAL FEASIBILITY

By Maeva SABRE (CSTB, Fr)



The state of the art about the rules and legislative aspects is based on the Kelsen pyramid model. The approach is based on directives at the European scale, then at the national scale, and finally at the local scale; it encompasses the 4 construction, energy, agriculture, and socioeconomic sectors.

European scales has more levers available for implementing greenhouses on rooftops. The point here is that construction regulations vary depending on the project, its scale and its location. Specialist advice should be sought for and followed. General directives orient sustainable development so as to allow for various fields of action. They favour innovations, functional and social mixing, and the preservation of natural heritage.

Obstacles increase at the local scale because of many regulations related to the diversity of sites, to urban configuration and to the typology of buildings. Obstacles can increase even more at the construction scale, where they are related to technicality, implementation, use, and people's health and safety.

At the construction scale per se, the project can present two different configurations with their own obstacles : i) existing buildings (for renovation), and ii) new buildings.

Then, the typology of the rooftop greenhouse (RTG) (production / community / technical greenhouse) involves different ways of functioning with their own inherent obstacles, whether from the construction, energy, or farming points of view. The function of the RTG will determine which regulations it should abide by.

On an existing building, two main obstacles are likely : one is related to construction, and the other to the use of the greenhouse itself : the host building structure implies limitations for the greenhouse morphology and the farming system (conventional, hydroponic, etc.); the greenhouse use will define the issues related to energy operation and to people's health and safety. Integration in the food-processing and economic environments also deserves to be addressed.

On a new building, obstacles are less on the construction and regulatory aspects because these have been tackled upstream. They are more linked to the economic model of the farming activity and social investment.

Although regulations differ among countries and regions, common obstacles exist. They include :

- Building permits
- Building controls
- Regulations related to public calls for offers
- The maximum constructible height depending on the size of the building
- Constraints related to installing a crane on a busy street
- Authorised construction budget
- Public reception constraints
- Environmental (or ecological) compensation
- The limitations set by development plans
- The operating permit
- Rights of light
- The trade permits
- Health regulations
- Health risks
- Food safety regulations
- Construction and horticultural production labels

For each of these points, it is also important to clearly identify the interlocutor who will help the project progress.

For example :

- Cities, towns, local authorities
- Urban planners
- Urban project managers
- Developer / owner / property manager
- Companies / operators
- Design offices

PREPARATION

SOCIAL ASPECTS

By Susana Toboso (UAB, Es), Xavier Gabarrell (UAB, Es), Gara Villalba (UAB, Es), Cristina Madrid (UAB, Es), Ramiro Gonzalez (UAB, Es), Caroline BINI (Groupe One, BE)

OPERATIONAL STEPS OF THE SOCIAL ANALYSIS

A wide range of methodologies – quantitative ones and qualitative ones – are used for social analysis. In this case, we advise using different methodologies at different stages of the project. See figure below for a better understanding.

HOW ?

Stakeholder mapping

Collective workshop

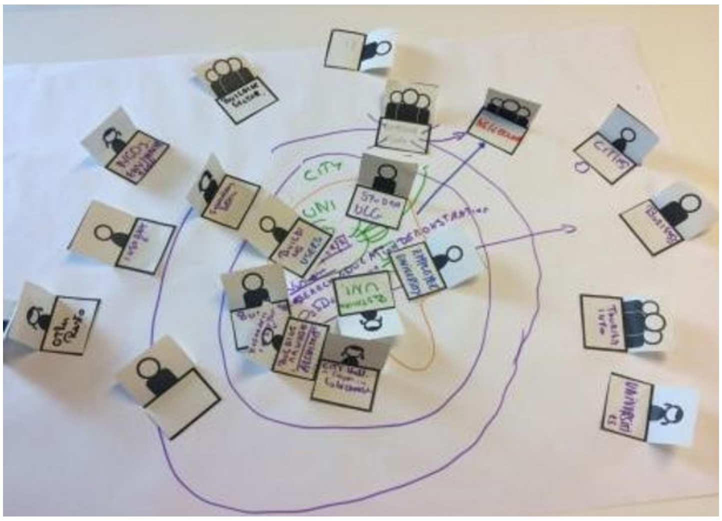
The project leader organises a workshop to develop a matrix of the key stakeholders of the pilot process with his/her team : potential rooftop greenhouse (RTG) users, current users & owners of the building, local authorities, neighbours, etc.

How to do the mapping workshop :

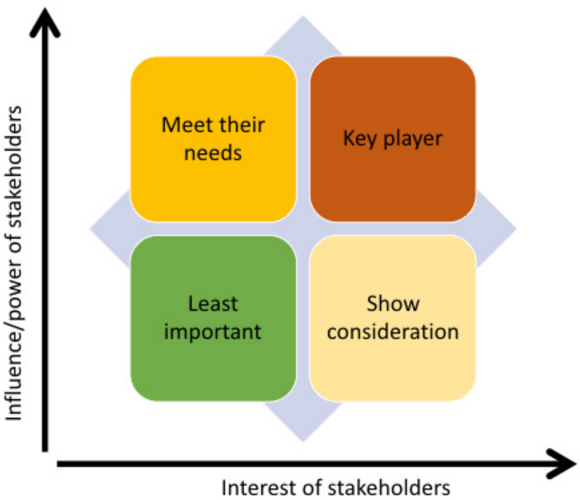
1. In the centre, write the pilot vision. Why was this pilot created ? "Why" according to Andreas Gaber

See this video of Simon Sinek

2. Identify all the stakeholders of your project.
3. Identify all the existing flows between your project and the stakeholders. Identify all the existing flows among the stakeholders. Are they monetary, informational (one-way) or collaborative (two-way) flows ?
4. Be creative and think about all the new flows you could create among all these entities.



BUILD A MATRIX



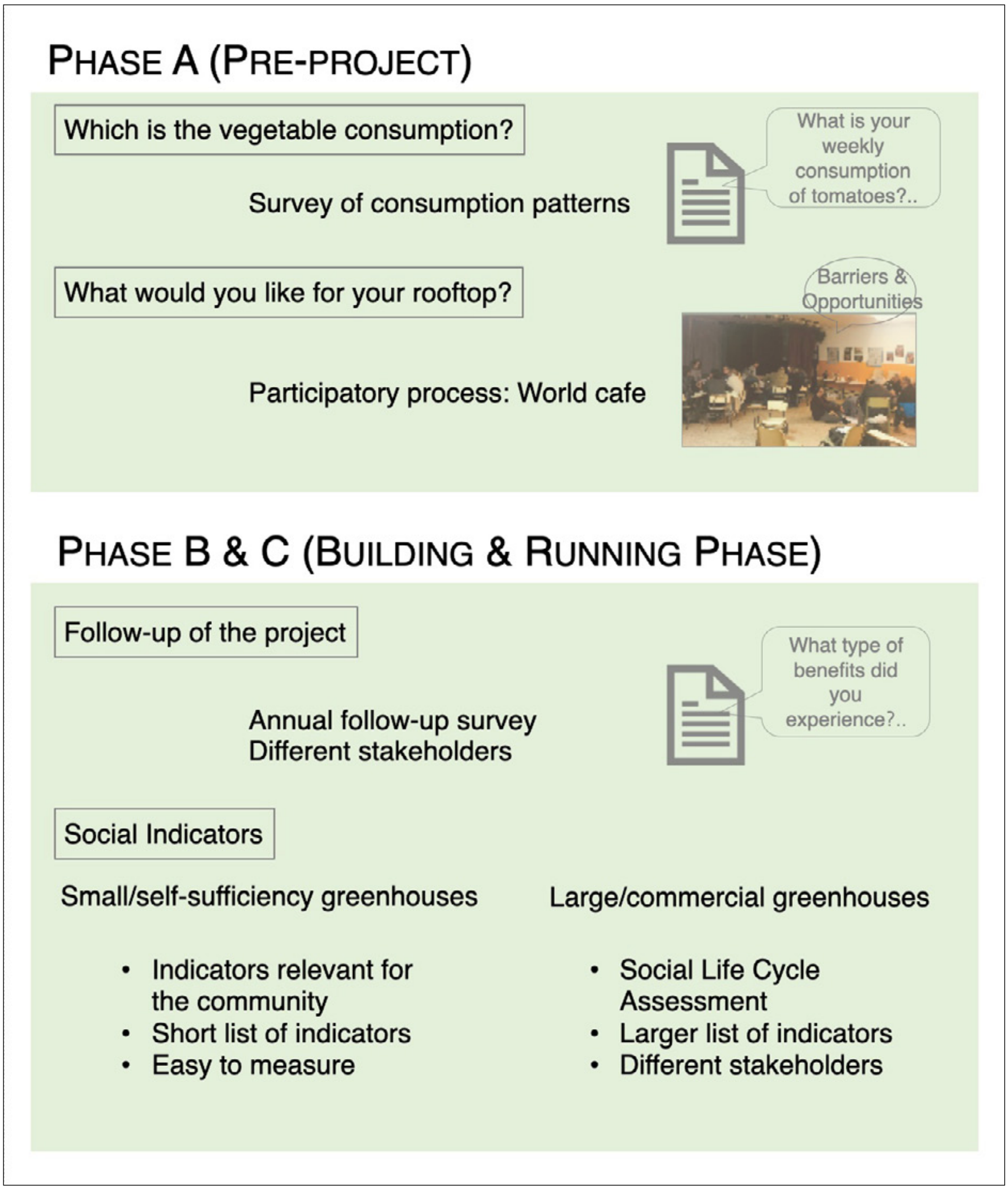
List all the stakeholders in a table. Then, identify their needs and their power (figure below) and select who are the key players; these key players will be the most important targets of your communication/actions, in order to maximise the success of the RTG implementation. They should be invited to the participatory process (see aside).

Introduction | Preparation | Execution | Exploitation | Feedbaks | Pilot Projects | FAQ

STAKEHOLDER ENGAGEMENT STRATEGY

Write down an action plan based on the mapping exercise for efficient stakeholder involvement, e.g. bilateral consultations, public events, invitation to the participatory process, etc.

Prepare a consumption pattern questionnaire that will characterise the metabolic patterns of the residents. It will help to know the actual food requirements of the residents and plan the crops accordingly in the greenhouse. (e.g. [https ://doi.org/10.5565/ddd.uab.cat/226152](https://doi.org/10.5565/ddd.uab.cat/226152))



Participatory process

The participatory process will analyse whether implementing a rooftop greenhouse (RTG) is relevant. We propose the world cafe method for stakeholders to agree on what they want. The world cafe is based on a constructive conversation related to critical questions and collaborative learning. It assumes that the knowledge that we are searching for is already present (Fouché and Light, 2011). This method is particularly useful to make sure that a topic is investigated from different perspectives and that everyone in the room is contributing to the conversation. The method is based on several rounds of conversations in small groups (4-5 people) for different opinions and perspectives to be expressed in a relaxed environment. It can be employed to gather the residents' preferences for the implementation of food, energy, or/and water, and greenhouse systems on the roofs. The essence of the methodology lies in conveying the message that ideas are being shared, in a competition-free manner, simply by exploring possibilities (Brown, 2005).

The main steps of the methodology are as follows :

- Invite participants to take part in a face-to-face session
- Organise a working team to prepare the session (4/5 people) depending on the number of participants. This team will prepare the topics to be discussed in each small-group conversation, technical support, and the hosts will be in charge of coordinating the groups and noting down all the comments
- Prepare the discussion tables and the place where the discussion will take place so that all the participants feel comfortable, with 4/5 people table and a projector to show the questions. All participants will sit at all tables, answer all questions, and mix with all other participants to reach more richness and criticism in the answers. One host table will collect all opinions, and the discussion time will be no longer than 15 minutes. The hosts will be in charge of collecting all information, and this information will be coded and analysed later.

(http://bcnroc.ajuntament.barcelona.cat/jspui/bitstream/11703/116237/1/Cobertes_Mosaic.pdf)

More complex urban planning methodologies can be applied, e.g. the Roof Mosaic methodology (Toboso-Chavero et al., 2019).

This methodology combines life cycle assessment with two rooftop guidelines. It was applied to a neighbourhood. The aim is to analyse the technical feasibility and environmental implications of producing food and energy and harvesting rainwater on rooftops through different combinations at different scales. See an example of this methodology in the paper published in the Journal of Industrial Ecology, https://doi.org/10.1111/jiec.12829.

The Roof Mosaic can be combined with the study of the metabolic pattern using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) of the area under study and different participatory processes, as shown see Figure of the SOCIAL ASPECTS part in the Chapter EXPLOITATION. This methodology was applied to housing estates (Toboso-Chavero et al., 2020).

Other multi criteria analyses can also be performed, e.g. a sustainability analysis using the Integrated Value Model for Sustainability Assessment (MIVES). MIVES is a Multi-Criteria Decision Making (MCDM) methodology based on the Multi-Attribute Utility Theory (MAUT) with a value function concept, designed to perform quantitative and objective assessments. See an example of this methodology in the paper published in Science of Total Environment.

https://doi.org/10.1016/j.scitotenv.2018.01.191.

EXECUTION

COMMUNICATION TIP

EXECUTION PHASE

CONSTRUCTION OF ROOFTOP GREENHOUSES

SOCIAL ASPECTS

COMMUNICATION TIP

By Caroline Bini (Groupe One, BE), Mathilde Gougeau (Groupe One, BE)

As you are starting to focus more on the development of your product and/or service offer, it is important to go back to your initial communication strategy to resume it according to your new goals in terms of communication and promotional actions as well as event planning. It might be that your target audience changed depending on your project development, then you might have to rethink your promotional strategy on communication channels accordingly. See Communication chapter.

For instance, if you notice that your most active audience is composed of young people mainly using Instagram as a communication channel, you may have to develop your social media strategy mostly through this channel.

You may also have decided, for financial reasons and after an in-depth analysis of the market and the neighbourhood, that you will start selling vegetable baskets to the local community. In that case, you will have to promote your product locally by developing local events, spreading the news throughout the neighbourhood via posters and flyers, and be more active on social media by developing a promotional campaign on this new product. Your message may also change because your new goal will be to attract people by focusing on the local aspects of your vegetable production and you will have to focus more on the community aspects of your project.

COMMUNICATION TIP

EXECUTION PHASE

CONSTRUCTION OF ROOFTOP GREENHOUSES

SOCIAL ASPECTS

CONSTRUCTION OF ROOFTOP GREENHOUSES

By Nicolas BRULARD (Fermes de Gally, Fr), Ismael BARAUD (CSTB, Fr)

INTRODUCTION

This chapter focuses on the construction works of the building and the greenhouse. It is intended to guide users toward the achievement of a project. It provides explanations about the supplemental chapter required in the Special Technical Specifications (STSs). It suggests a glossary and terms used to specify the greenhouse description. It is aimed for architects, urban planners, building contractors, etc.

According to the rules and regulations of each country, the method and the documents written by each stakeholder should be adapted to comply with usual local methodology and rules.

Bellow : Construction site of Chapelle International, Paris (France)

In France for example, the first step of a project consists in writing a project outline draft (POD). This document describes the general purpose of the project.

Then a project final draft (PFD) is written. This document describes the technical solutions and provides details about the project budget.

Then STSs are written. These documents describe the supply and execution of each part of the building, with the product specifications, the methods of execution, performances, and specific purposes.

In addition, STSs are a contractual document between the project manager and the owner and are specific to each operation. Their full drafting is the responsibility of the project manager, both in form and content.

The present section is not intended to provide a "typical" description of a rooftop greenhouse (RTG) structure, which is the subject of a special section in this document.

There exists a common basis as to how to write each group of specifications for the construction of a building. RTG construction should therefore comply with these rules.

Five main execution blocks can be distinguished for the construction of RTGs.

- the structural work part, related to masonry, preparation of walls, ceilings and structural anchors, accesses (lifts, stairs)
- the waterproofing package, related to the flat roof work, ensuring the enclosure, and covering of the underlying building
- the RTG structure batch, related to the structure bearing the greenhouse and its envelope, including climatic regulation (shading, openings, walls, etc.)
- the plumbing batch, related to incoming and outgoing fluid equipment and networks, and their connection with the building networks
- the electricity package, related to control devices and electrical supply / communication networks, and their connection with the building networks

Generalities

The next part of this document provides guidelines about the following steps of the construction work:

- Design
- Flat roof diagnosis
- Preparation works
- Acceptance of works before building the greenhouse structure
- Greenhouse structure works
- Greenhouse outer envelope works
- Greenhouse interior design (except cultivation equipment, irrigation, etc.)
- Acceptance of works after the construction of the greenhouse structure
- Focus on the as-built file

For each step you will find a general description of the items to be included in the project STSs and FDW so that the subcontractors can respond correctly to the owner's tender for an RTG.

Design

STSs will include all the additional information required to build a greenhouse on a roof as compared to traditional roofs. A building information model (BIM) should be designed for easier management of the works.

Several suggestions are made in the FDW to allow contractors to adapt to the specificities of the project, select products and processes, etc.

Several added values / impairments are also suggested.

Specifications for each work section (structure, envelope, plumbing, electricity) are included in the present section.

Documents

- Documentation on the execution of works, descriptions
- Plans, details
- Construction site quality plan
- Technical documents of the processes to be used.

Preparation works

In case of an existing flat roof, the FDW will describe the preparation works like carrying out a diagnostic study of the flat roof and extra preparation works specific to the situation of the building.

List of stakeholders on the construction site

- RTG promoter
- Contracting authority
- Architect
- Project management (structural works, waterproofing, greenhouses, plumbing, electricity, etc.)
- Control office

FLAT-ROOF DIAGNOSIS

The flat-roof diagnosis provides information about the existing structure and about the composition of the structures ensuring the closure and coverage, and give a description of all the preparation works (foundations, braces, refurbishment, shadowing, load, wind exposure, etc.). The STS should.

- describe how to perform this diagnostic analysis (documentary analysis, sampling, tests, calculations)
- describe which document will approve the feasibility of the works (report, statement, technical approval delivered by authorities, etc.)
- indicate the overload hypothesis and descent of loads on the building structure, and what measurements need to be checked
- calculate the excess capacity of the foundations
- calculate the risk of uplift wind load and the constraints applied to the RTG structure

EXTRA PREPARATION WORKS

The STS will indicate all the extra preparation works related to the greenhouse construction. It will cover all security aspects (scaffolding, safety) and supply chains, a place for storage, crane installation, waste management, energy supply for the construction works, facilities, etc.

The enabling works will also include modifications on the roof, e.g. removing tiles, pedestal and slab protection or granulate, waterproofing reinforcement, creation of a new access, displacement of existing equipment (ventilation outlet, rainwater inlet pipe) on the roof, drilling for pipes or cable sheaths, creation of concrete pillars or slabs, methods of mechanical anchoring of the greenhouse to the roof, etc.

ACCEPTANCE OF THE PREPARATION WORKS BEFORE THE GREENHOUSE CONSTRUCTION

The STS will specify all the steps of the works that require acceptance before the greenhouse structure is built.

In case of claims, corrective actions will have to be started before starting to build the RTG structure.

- Warrant protection
- Signature of the RTG manufacturer

GREENHOUSE STRUCTURE AND ENVELOPE WORKS

The STSs will take specific conditions into account when the greenhouse is built on a roof as compared to a traditional greenhouse built on the ground.

Aside : The structural anchoring of a greenhouse on an existing roof is specific

INTERIOR LAYOUT OF THE GREENHOUSE AND PRODUCTION DESIGN

The STSs should highlight specific organisation elements linked to the construction of a greenhouse on a roof. They will clearly focus on technical constraints and the non-accessible zone. Some of these specific elements are :

- the technical floor
- energy transfer connections with the building
- a safety shields
- pillar protection
- kick rails
- signage, user's circulation, access management
- training sessions
- localisation of anchoring points and hanging points
- selection of contractors
- localisation of water supply pipes, heating and air supply pipes

Aside : The interior design will define the localisations of the different energies.

e.g. : a greenhouse for growing tomatoes on culture bags, low temperature heating on the ground and suspended gutters.

Picture taken by GROOF team when visiting BIGH farms at Anderlecht, Belgium.

Maintenance facilities

The STSs will describe the required maintenance operations. In France, it is recommended that the project manager provide a maintenance file for the structures when they are innovative.

Management of adjacent facilities

Rooftop farming requires using adjacent facilities besides the greenhouse itself. The STSs will also need to foresee interaction flows and the related specific facilities and materials.

Management of regulatory aspects (fire, safety, noise, comfort)

The STSs will describe the measures taken to comply with fire, noise, safety and comfort regulations, as well as impact studies and specific monitoring procedures.

Acceptance of elevation and layout works

The STSs will specify elements linked to the construction of an RTG compared to a traditional greenhouse build on the ground:

- Focus on the as built file
- Future maintenance (preventive, curative)
- Maintenance and cleaning programs
- Annual maintenance, facility checks
- Heavy overall renovation.

COMMUNICATION TIP

EXECUTION PHASE

CONSTRUCTION OF ROOFTOP GREENHOUSES

SOCIAL ASPECTS

SOCIAL ASPECTS

By Susana Toboso (UAB, Es), Xavier Gabarrell (UAB, Es), Gara Villalba (UAB, Es), Cristina Madrid (UAB, Es), Ramiro Gonzalez (UAB, Es), Caroline BINI (Groupe One, BE)

This part can include indicators (see methodology in the exploitation phase) to analyse the social aspects within the two possible groups of installations, namely :

- small rooftop greenhouses (RTGs) for self-sufficiency,
- large commercial RTGs.

Indicators related to health & safety can be used such as noise levels, dust levels or any indicator aimed at measuring the possible inconveniences linked to the construction of the infrastructure. See the complete methodology in the exploitation phase.

It is also important to think about communication with your key stakeholders, e.g. neighbours, during this construction phase for them to understand your project and accept it.

EXPLOITATION

COMMUNICATION TIP

By Caroline Bini (Groupe One, BE), Mathilde Gougeau (Groupe One, BE)

As your production is increasing, your project may also evolve and lead you to modify your communication strategy. You may need to invest more time and money on promoting your services and products, and hire a communication officer or an event planner who will manage your daily social media, press campaigns, website, video productions, events, and so on. At this stage, it is essential to schedule your various communication actions to organise the workload and the people needed to develop it at best in order to achieve your economic goals and sell your products or services.

See in particular points 4 and 5 in general communication chapter.

EXPLOITATION

COMMUNICATION TIP

EXPLOITATION PHASE

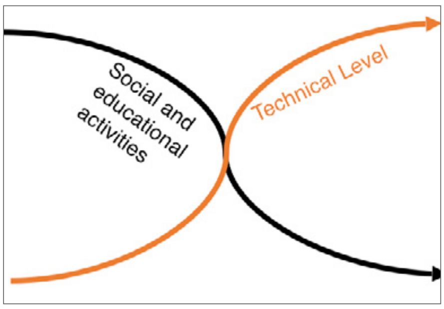
ROOFTOP GREENHOUSES CLIMATE MANAGEMENT

By David VOLK (EBF, DE), Guillaume Morel-Chevillet (ASTREDHOR, Fr)

IDENTIFICATION OF THE MAIN GOALS AND WISHES OF AN RTG PROJECT

Prior to choosing the right greenhouse or the best plants, a perfect understanding of the project's goals, target consumers, and stakeholders' wishes is necessary ((see SOCIAL ASPECTS part of the Chapter PREPARATION)). In fact, the more complex technical conditions are, the more difficult they are to be used by the public for social or educational activities.

If the priority objective is food production, specific technical choices are required. Limited resources restrict the possible outcomes. Clear objectives make a project more rewarding. The diagram aside summarises this idea.



Introduction
Preparation
Execution
Exploitation
Feedbaks
Pilot Projects
FAQ

ANALYSIS OF THE ENVIRONMENTAL CONSTRAINTS (BUILDING, WEATHER, SHADOW, HEIGHT, ETC.)

A comprehensive analysis of the project itself, based on environmental understanding, is a key to success for crop and climate management. Shadow from surrounding buildings or trees or even from the greenhouse structure and equipment (columns, braces, or pipes) will have an important restrictive effect on the yield if plants are not chosen carefully. Weather conditions such as prevailing wind, rainfall, or winter and summer temperatures will have an impact on the technical choices (greenhouses, equipment, plant selection). The building itself must be taken into consideration (roof lift, freight lift, security, opening hours, etc.) (see TECHNICAL FEASABILITY part of the Chapter PREPARATION).

GREENHOUSE TYPE

Choosing a greenhouse style is heavily dependent on the planned production, available space, and accessibility to the building.

Tunnel

A tunnel greenhouse is generally the cheapest greenhouse style. It only consists of an arched light-weight steel frame usually covered by PE (polyethylene) film. This leads to a low weight profile and makes the tunnel applicable for rooftops (but mind the wind factor). On the other hand, the tunnel greenhouse offers restricted room for currently available aboveground growing techniques. Due to its very simple construction, technical equipment, insulation, and ventilation are limited.

Chapel

The chapel (or multi chapel) greenhouse is usually made of a strong steel structure covering several meters with a gabled roof. Due to this shape, the greenhouse can be anchored into the structure of the host building. As a chapel greenhouse has a larger roof, its ventilation properties are reduced, unless they are compensated for by sidewall or forced ventilation.

Venlo

The Venlo greenhouse style is comparable to the chapel style, with several smaller "chapels" giving the greenhouse a "saw-tooth" look, adding more possibilities for ventilation. Since the Venlo style greenhouse is the industrial standard, it is comparably cheap, and all available greenhouse equipment is well adjusted in size and connection. Please note that placing a greenhouse on a rooftop will lead to smaller-scale projects than for on-ground greenhouses. This decreases the financial interest for a greenhouse construction company unless the wall is already built.

Lean-to

The lean-to greenhouse is based on a classical design that has been found in England since the Victorian Age and is commonly used to this day in China, with heavily insulated side walls and an arched transparent opening. The lean-to style has a lot of advantages as to the energy demand and the extension of the growing period. However, it needs to be facing exactly south, and this reduces opportunities on a rooftop. Additionally, while the lean-to style greenhouse is cheaper to operate, it comes at a higher initial investment cost and brings a higher load to the rooftop except if the wall is already built.

ORIENTATION

Installing a greenhouse on a rooftop comes along with some restrictions in placement and accessibility that are important to examine before construction can start.

The greenhouse will need constant sunlight exposure to offer the required growing conditions. In an urban context, higher buildings or trees may generate shadowing and reduce the light flux into the greenhouse. Furthermore, the orientation of the greenhouse may be not ideal and lead to income losses, which must be considered (cf. Bankruptcy of Urban farmer report). A north-south orientation optimises production and minimises shading effects.

SIZE AND SCALE

The size of the greenhouse is an additional factor to be considered. Identifying buildings designed and built according to the north-south orientation constitutes a relevant prospective list of buildings on which a rooftop greenhouse (RTG) can be installed with effective performance. One of the biggest advantages of urban farming is the locally produced food directly distributed in the surrounding area. Therefore, the RTG must supply the local market or demand to meet the needs of local residents. Too large a greenhouse relatively to local needs may lead to overproduction and failing to sell all goods or having to export them further away from the production site. Moreover, it is difficult to expand surfaces in an urban context. Each RTG has to be viable on its own or until it becomes part of network of RTGs.

ACCESSIBILITY

The roof accessibility is also important (see CONSTRUCTION OF RTG part in the chapter EXECUTION)). Greenhouses are under constant influxes and outfluxes of materials that need to be transported daily from the roof to the ground and the other way around. Building a large greenhouse on a large rooftop with no accessibility will lead to a bottleneck operation.

COVER MATERIALS (GLASS, RIGID PLASTIC, FILMS…)

A few covering materials are available from the greenhouse industry. The covering material itself is key for generating heat in the greenhouse, keeping it inside and creating a shell to keep climate conditions inside stable.

Glass

The traditionally used material in a greenhouse and also on the building facades is glass. It is a well-known material used both in the construction and agricultural sectors. Glass is comparably expensive but can provide the best insulation for a traditional transparent covering material if it is double or multi glazed (usually 6-8mm). It has average transmissivity properties that reduce the number of required layers. It has a long lifetime, but if it gets shattered the crops underneath cannot be sold anymore. Furthermore, glass is the heaviest greenhouse covering material. In the case of greenhouses occupying an entire roof, breakage implies a risk of broken glass falling around the building, i.e. a risk for users. It is preferable to leave an area free of traffic all around the RTG to eliminate this risk and to allow for the replacement of the glazing as easily as possible.

Polyethylene

The roof accessibility is also important (see CONSTRUCTION OF RTG part in the chapter EXECUTION). Greenhouses are under constant influxes and outfluxes of materials that need to be transported daily from the roof to the ground and the other way around.

Building a large greenhouse on a large rooftop with no accessibility will lead to a bottleneck operation.

Polycarbonate

This material comes in rigid sheets that are often used in greenhouse coverings and also on building facades. It is a well-known material used both in the construction and agricultural sectors. The sheets can be made of multiple layers and can achieve good insulation standards while still generating good transmission. They have an average lifetime but are easily replaced.

ETFE

ETFE is a modern film material that is more and more used in the greenhouse business. The film is highly transparent and durable. Due to its UV-transmission properties, it has a high lifetime of over 20 years. As a single layer it has basically no insulation properties, but it can be installed as a double layer or cushion for average insulation properties. The greatest disadvantage of ETFE is its high price (up to 15 €/m²), which may evolve over time.

EXPLOITATION

COMMUNICATION TIP

EXPLOITATION PHASE

MANAGEMENT OF RAINWATER FOR THE SUPPLY OF ROOFTOP GREENHOUSES

By Bernard de Gouvello (CSTB, Fr)

In RTG operations, water requirements are often high, resulting in significant management costs. Therefore, it may be relevant to use rainwater from the greenhouses themselves, or even from the surrounding roofs located within the same plot[1].

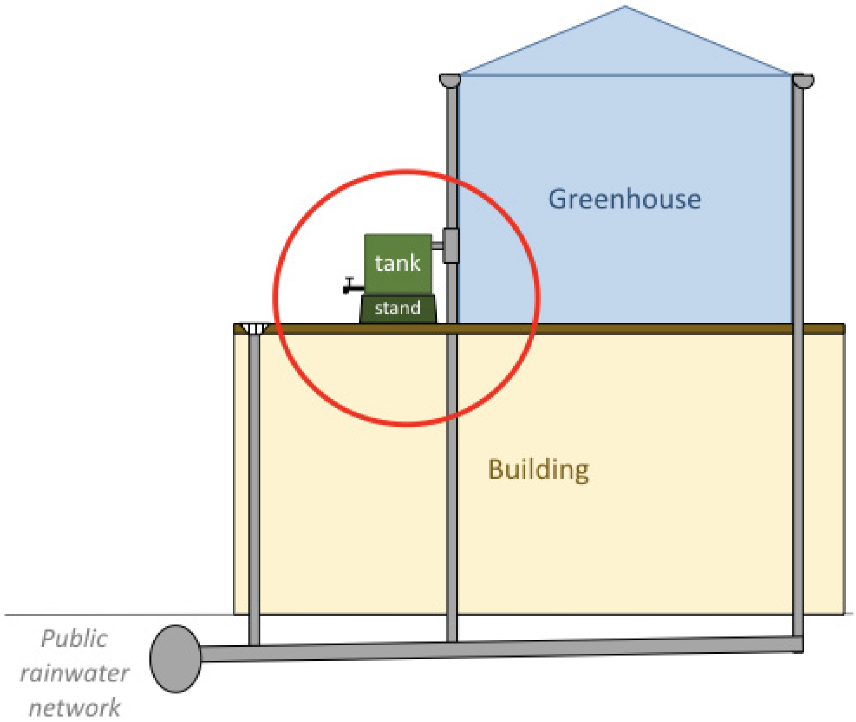
Two configurations are available to use the rainwater from the greenhouses and other surrounding roofs :

- storage on the rooftop;
- storage at the bottom of the building (on the ground, in the basement, or belowground).

1 *In the case of very large needs in terms of roof surfaces suitable for water collection, the recovery of water from surrounding roofs – i.e. outside the project plot – can be studied. A specific legal act may be required to implement this solution in order to be compatible with ongoing national regulations.

CONFIGURATION 1 : ROOFTOP STORAGE

The storage tanks are placed directly on the flat roof near a downspout from which they collect water from the corresponding roof portion through a bypass system installed on the downspout that includes a 1-mm mesh filter (French decree of August 21st 2008).



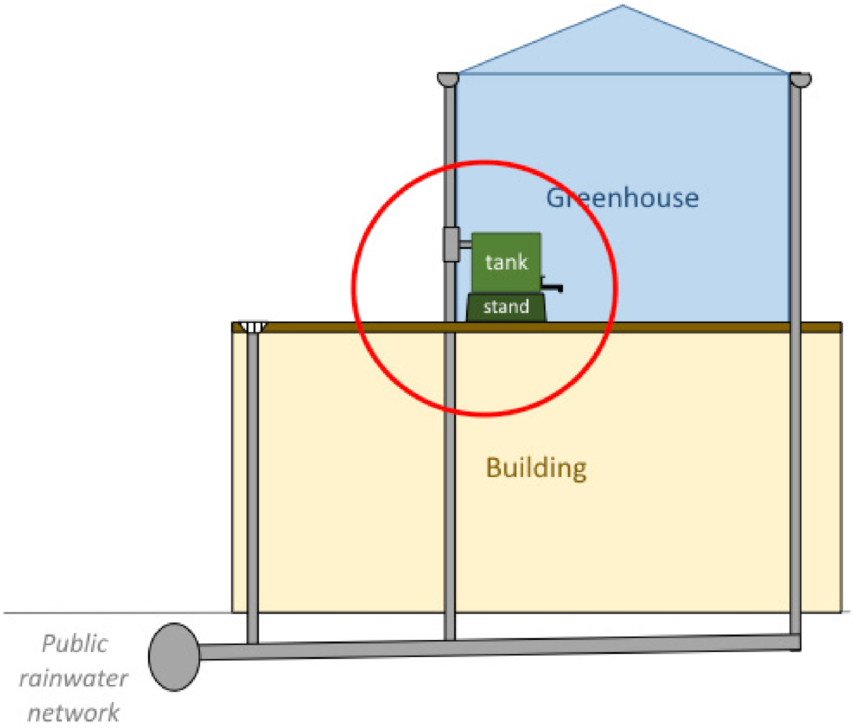
The water inlet of the tank also serves as an overflow : excess water flows down the downspout and into the public rainwater network.

The tank is placed on an elevation stand so that the tap at its bottom can feed a watering can. This tap is also used to completely empty the tank during the winter period when the bypass system is bypassed.

A sign indicating "non-drinkable water" and an explicit pictogram (in accordance with the French NF X 08-003-1 standard) should be affixed near the tap.

In this configuration, the use of rainwater constitutes a rather marginal supplement from a quantitative point of view. Its main purpose is to educate and raise awareness of the use of alternative resources to drinking water for watering.

VARIANTS



Please note that this case may occur in particular when the downspouts are located inside the greenhouse. It may also be appropriate if the greenhouse floor is more robust than the flat roof floor and can therefore bear a higher load.

Advantages

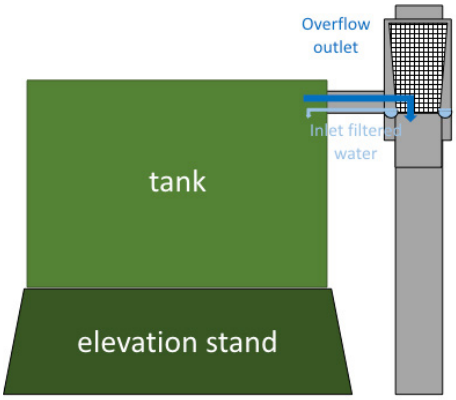
- low cost
- ease of installation : there is no need for a professional installer
- very simple handling (no electricity required)
- possibility to install several tanks (one per downspout)

Constraints and possible weak points

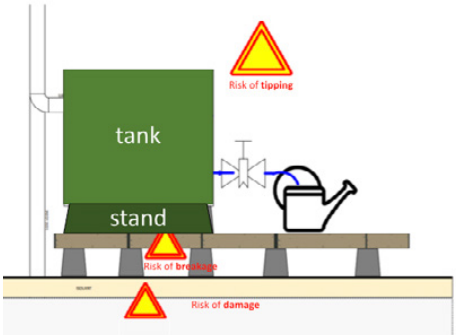
Main constraints :

- this system is only possible if the mechanical characteristics of the rooftop allow for it; it requires precautions when implementing it (see bellow possible weak points)
- the outdoor tank(s) must be emptied in winter to avoid degradation by frost.

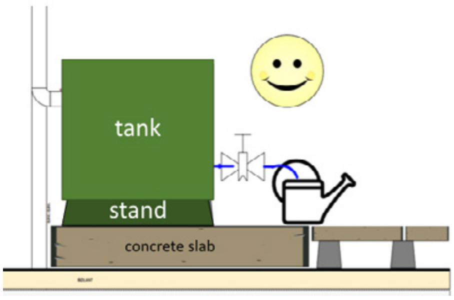
Possible weak points :

- check the lid for tightness to prevent mosquitoes from developing. This is particularly important if the tank is located inside the greenhouse (increased risk of mosquitoes)
- Prefer dark or black tanks to avoid algal growth
- Ensure that the “non-drinkable water” signs are legible and replace them if necessary.
- 

  Make sure that the connection to the gutter – bypass and overflow – is made correctly.

- 

  The tank must not rest on slabs because this entails several risks : tilting of the tank, breaking of the slabs, deterioration of the studs and even of the insulation material.

- 

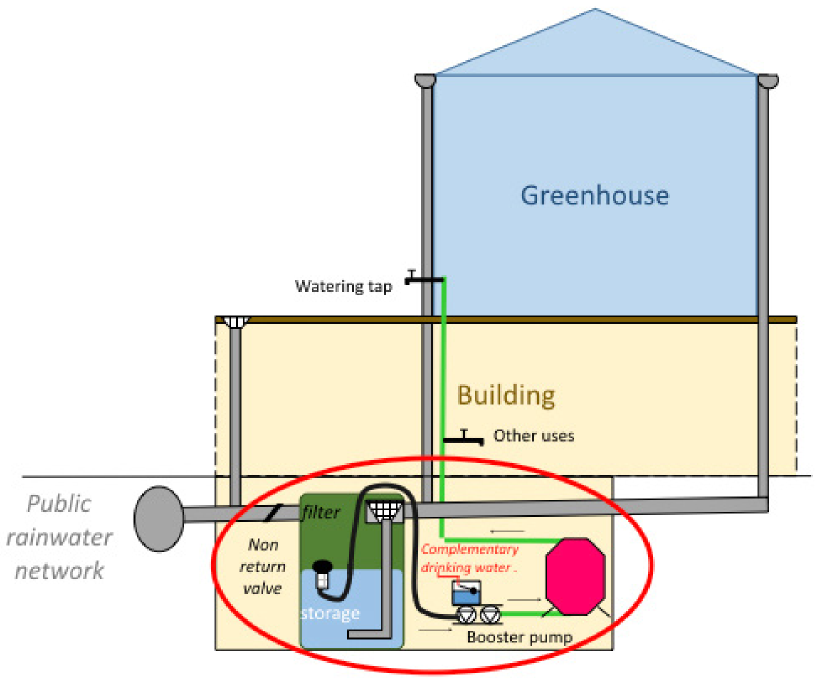
  It is preferable to have it rest on a concrete slab which allows for the weight to be better distributed on the floor.

Introduction
Preparation
Execution
Exploitation
Feedbaks
Pilot Projects
FAQ

CONFIGURATION 2 : STORAGE AT THE BOTTOM OF THE BUILDING

PRINCIPLE AND APPLICATION SCOPE

Water from the various downspouts in the greenhouse (and from other inaccessible[2] roofs if necessary) is channelled into a tank located at the bottom of the building[3]. The buried network of pipes feeds the tank. A suction strainer attached to a mini buoy and connected to a booster pump by a flexible hose allows for the water to be drawn from the upper water table, which guarantees a better quality (less suspended solids). The booster pump allows for the water to be returned to the greenhouse for use via a pipe and a tap.



A sign saying "non-drinkable water" and an explicit pictogram should be affixed in the immediate vicinity of the point of use. The return pipe will be labelled with the same information, particularly before and after passing through any partition or floor. In order to ensure water availability at the service tap located on the flat roof supplied with rainwater, a supplemental tank supplied with drinking water and having an AA or AB disconnection in accordance with the EN 17117 standard may be placed in the technical room. A three-way valve is used to switch between rainwater and water from the supplemental tank.[4].

2 In the French case, the scope of the decree of August 21, 2008 is limited to inaccessible roofs

3 Three different locations are possible: (1) buried (requiring available terrain, an earthmoving operation, and the use of a tank with mechanical characteristics compatible with the constraints of the terrain); (2) on the ground itself (which limits the possibility of recovering water from several drops, unless it is agreed to have a horizontal pipe network, which is unattractive); (3) in the basement (which requires having a really available space but it is the most interesting option and it is the one shown in the diagram).

4 This addition (which makes the project more complex and expensive) can be avoided if a drinking water tap can be connected directly to the rooftop. In this case, when water runs out in the tank, greenhouse users use this second tap.

Finally, a filter is placed at the tank inlet, and the tank overflow is protected by a siphon or a non-return valve (as shown on the diagram).

In this configuration, which is technically more demanding, the use of rainwater is a significant quantitative addition in terms of water requirements for uses that do not require drinking water quality for the entire building. The use of rainwater in the greenhouse is only one use among others. In particular, the collected water can also be used for toilets, a technical tap for cleaning, etc.

VARIANTS

There are many possible variants as regards storage location and the organisation of the disconnection device. These different configurations are not specific to greenhouses. They are widely described in guides or leaflets, in particular the ASTEE (the French association of water and waste professionals) guide and the booklet published by the French Ministries of Ecology and Health (see references 2 and 4). These documents are essentially technical, so they are available in other countries.

ADVANTAGES

- allows to collect more water by collecting it from all the downspouts from the roofs of greenhouses and other inaccessible roofs
- allows for the use of rainwater throughout the year, therefore greater substitution rates.

CONSTRAINTS AND POSSIBLE WEAK POINTS

Main constraints :

- significantly higher installation costs
- a professional plumber experienced in this type of installation will be needed
- a maintenance procedure – possibly performed by a third party – will have to be set up.

Possible weak points :

- be careful not to connect water from the flat (accessible) roof itself to the tank, which can turn out to be complicated in practice in some cases
- dedicate a clear space to the technical installation, in which the schematic diagram and the sanitary notebook of the installation can be found. These documents must be protected from deterioration by humidity[5]
- tanks should be cleaned yearly to prevent dead volumes from forming inside and the buildup of deposits

5 It is recommended to plasticize the schematic diagram.

Please note metering to determine the volume of water saved is appropriate for large installations. However, if the installation includes a drinkable water supplement, two meters will be installed : one at the outlet of the booster pump, the other at the inlet of the supplemental tank (to subtract the volume of rainwater substituted for drinkable water).

References for further information on rainwater harvesting and use

Please note apart from the standard (which has a European outreach), the references given below relate to France. However, comparable elements are bound to exist in the other partner countries of the project.

1. AFNOR, 2018NF EN 16941-1, On-site non-drinkable water systems - Part 1 : systems for the use of rainwater.

   This European standard has replaced the various standards previously existing in several European countries (Germany, Great Britain, France in particular).

2. ASTEE (Association Scientifique et Technique pour l'Eau et l'Environnement), 2015, Guide Technique Récupération et Utilisation de l'eau de pluie. Informations et recommandations relatives à la réalisation de dispositifs utilisant les eaux issues de toitures et stockées in situ (coordination : B. de Gouvello). Paris : ASTEE, 65 p. (https://www.astee.org/publications/guide-sur-la-recuperation-et-utilisation-de-leau-de-pluie)

   This guide, intended for private individuals, construction and urban planning stakeholders (public or private project owners, project managers, design offices), as well as managers and executives of water and wastewater services, has a dual purpose : (i) to provide a synthesis of current knowledge on the subject; (ii) to present, in an organized and coherent manner, a set of information and recommendations for the implementation of a project.

3. de Gouvello B., Noeuveglise M., 2007, Récupération et Utilisation de l'eau de pluie dans les opérations de construction. Retour d'expériences et recommandations, Paris : ARENE IDF, 64 p.

   (https://www.lamaisonecologique.com/wp-content/uploads/2016/12/recuperation-OARENE-CSTB.pdf)

   Written before the 2008 French Order, this guide presents in detail 8 examples of projects and a methodology for carrying out projects from their design to their operation.

4. Ministères en charge de l'Ecologie et de la Santé, Systèmes d'utilisation de l'eau de pluie dans le bâtiment Règles et bonnes pratiques à l'attention des installateurs, 20 p.

This small booklet produced by a group of experts explains the framework of French regulations with numerous explanatory diagrams.

5. Arrêté du 21 août 2008 « relatif à la récupération des eaux de pluie et à leur usage à l'intérieur et à l'extérieur des bâtiments » Available on legifrance.fr, this text constitutes the core of current French regulations on rainwater harvesting and use.
6. de Gouvello B., 2010, La gestion durable de l'eau : Gérer durablement l'eau dans le bâtiment et sa parcelle (illustrations Jean-Marc Lauby), Paris : CSTB Editions, 129 p.

   See in particular Chapter 2, specifically devoted to rainwater harvesting and use.

7. Alberto Campisano, David Butler, Sarah Ward, Matthew J. Burns, Eran Friedler, Kathy DeBusk, Lloyd N. Fisher-Jeffes, Enedir Ghisi, Ataur Rahman, Hiroaki Furumai, Mooyoung Han, Urban rainwater harvesting systems : Research, implementation and future perspectives, Water Research, Volume 115, 15 May 2017, Pages 195-209

COMMUNICATION TIP

EXPLOITATION PHASE

ROOFTOP GREENHOUSES CLIMATE MANAGEMENT

MANAGEMENT OF RAINWATER FOR THE SUPPLY OF ROOFTOP GREENHOUSES

MANAGEMENT AND FARMING SYSTEMS OF ROOFTOP GREENHOUSES

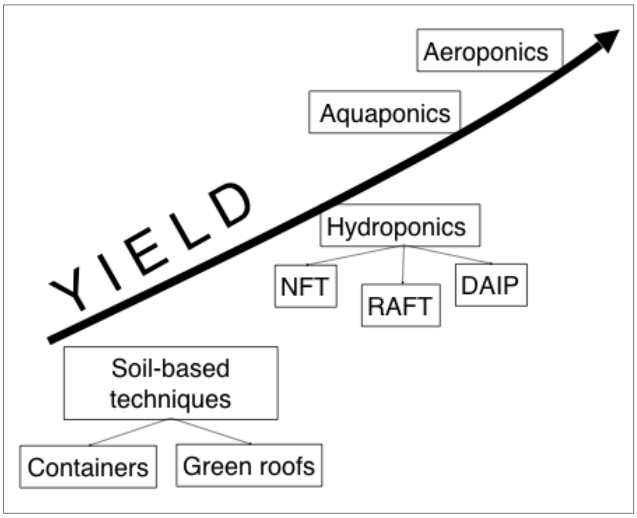
TECHNICAL, ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF ROOFTOP GREENHOUSES

SOCIAL ASPECT

MANAGEMENT AND FARMING SYSTEMS OF ROOFTOP GREENHOUSES (RTG)

By Guillaume Morel-Chevillet (ASTREDHOR, Fr), Veronica Arcas (UAB, ES)

Growing plants on a rooftop implies in most cases using soilless growing techniques, from substrate-based solutions up to hydroponics, aeroponics and aquaponics systems.



As explained in the diagram on the left, choices are mainly guided by project objectives, yield expectations, the roof bearing capacity, and the technical skills of the team.

SUBSTRATE-BASED PRODUCTION

Using a substrate-based production is the easiest way to grow plants. Depending on the substrate used this system might differ more or less from a hydroponic system, needing additional fertilization through irrigation or, on the other hand using soil and natural occurring structure and nutrients. With the use of soil, a larger reservoir of organic nutrients can be obtained effortlessly, while most substrates also will serve as good water storages needing less stable irrigation conditions. Nevertheless, it requires a specific quality of material in order to get a good agronomic growing medium (nutrient, structure, water retention, etc.), a mixture of raw materials, like the ones utilized as media in green roofs. Drip irrigation systems and a supply of slowly released fertilization is necessary if good yield is expected. As well a good water flow to reduce possible nutrient accumulation and greater salinity if nutrients are given through irrigation. The total substrate weight, when saturated with water, is a critical data point and needs to be known prior starting the project because generating loads between 200 to 400 kg/m². Moreover, after one or two growing seasons, a part of the substrate needs to be renewed (settling, loss of nutrient, etc.). Expected yield is less than 5 kg/m²/y for common vegetables. Nevertheless, using a substrate-based production would require less monitoring so less working force. It can be a good solution to create its own mixture of material from urban wastes for e.g. Prices are relatively low, between 10 € to 20 € per m², depending of the equipment (irrigation and fertilization). Possible substrates can be divided into two categories : organic and inorganic. The first category entails all substrates generated form organic materials like compost, coco fiber, pine bark, sawdust and peat moss. The second category can be again divided into inorganic media from natural sources, like sand, gravel, volcanic tuff, rock wool fiber, expanded clay and perlite. Or can be generated in a synthetic manner like foam or plastic.

Substrate based solutions on container can provide secure and sucessfull yields on lettuces, e.g., of the JB Hydroponics systems tested in ASTREDHOR Grand Est Station. Credits : Solène Batard.

HYDROPONIC/ AEROPONIC PRODUCTION

Hydroponics soilless growing systems recirculate nutrient solutions based on synthetic and mineral inputs (organic fertilizer remain a rare exception). It is important to have a great knowledge on the nutritional requirements of the crops as well as the capacity to routinely be able to check for the incoming and outgoing nutrients. This is even more relevant in case of water and nutrient recirculation. There are different forms of hydroponic systems :

- The Flood-and-Drain system where plants are grown in aggregate-filled containers placed in watering beds.
- The Drip-irrigation system commonly used to grow vine crops such as tomatoes, cucumbers or peppers. Plants sit in growth-medium-filled containers and nutrient solution drips onto the plant's root ball.
- The raft culture or deep-water culture which involves the submersion of plant roots in a nutrient bed solution.
- The Nutrient Film Technique (NFT), one of the most productive and frequently employed technics for leafy greens. Plants roots are suspended in a long narrow trough through which the nutrient solution trickles.

Hydroponic techniques provide good yield and are lightweight. They are also adapted to many plant species, e.g. GHE systems on lettuce, chard and peppers. Photo credits : Solène Batard.

While in hydroponics systems the plant root supply is based on fertilized water, in aeroponic they get water and nutrient from a fog. Both systems are lightweight (less than 50 kg/m²) and provide high yields, between 30 to 70 kg/m²/y depending of the plants species. Water consumption is also very low in comparison to substrate-based solutions. Investment cost is about 50 € up to 200 € (depending of the equipment quality and the installation procedure). Maintenance requires a good agronomical skill and in case of technical problem (such as power cut) the production can be quickly damage because of the lower resilience of this system. This lower resilience is due to the lack of any substrate or matter capable of holding water and nutrients in case of a lack of irrigation.

AQUAPONIC PRODUCTION

Aquaponics systems combine the benefits of highly controlled hydroponic systems with the qualities that natural, organic growing systems offer. A closed-loop nutrient system replaces the mineral and synthetic fertilizer use, with the self-fertilization based on fish wastes decomposed by bacteria. This system needs specific skills balanced between plants and fish production due to the complex systemic interactions. The fish storage requires at least 800 kg/m², whereas plant production bearing and the yields (30 to 70 kg/m²/y) are like the hydroponics system. Added up to the yield of crops, fish production can be implemented into the business plan as well. Cost for plants production are like hydroponic ones, but fish production required a specific investment (between 800 to 1 200 € / m²) and a good mastery about fish production.

Aquaponic production includes fish production and plant cultivation. It can provide multiple incomes for urban farmers with high technical skills. Here : APIVA (Aquaponie, Innovation Végétale et Aquaculture) pilot system in Astredhor - Aura station. Photo credit : Guillaume Morel-Chevillet.

Introduction Preparation Execution Exploitation Feedbaks Pilot Projects FAQ

CROP SELECTION

Plant choices must be done carefully in respect to the local market, consumer expectations, agronomic conditions, growing systems and technical skills. Plants cultivated for urban agriculture on RTG purpose can be divided like this :

Microgreens, leafy greens and aromatics

This range of plants is focused on leaves production (not flowers or fruits).

- The first leaves harvesting, called "Microgreens production", is a niche market. A large spectrum of species can be grown such as sunflower, beans, wasabi or mustard and the production circle is short (from 10 to 20 days).
- Leafy greens are also often grown by urban farmers because of the short expiry date and the freshness needs by the market. Lettuce, Kale cabbage, spinach or arugula are the most famous ones. The production schedule is likewise short (less than one month) and the same plants can be harvested a few times.
- Aromatic plants cover a large selection of the harvest. From the most common ones like basil, mint or Persil to the more original ones such as the Ice plant, Artemisia or Agastache. They can be sold fresh (cuttings leaves) or in small pots.

These products are grown is many urban farms because of their ultra-fresh quality and their high high-value prices (between 10 € up to 70 € / kg for micro-green for example). Under certain circumstances these aromatic plants may receive a BIO label which can lead to a higher economic value on the market.

Fruit vegetables (tomatoes, cucumbers, peppers, vine crops...)

Fruit vegetables are more complex to grow. They need more time and more maintenance, especially as regards fertilisation, but the final product (their fruit) is easily saleable and expected by customers. One of the main current challenges is finding species combining good yield with original colours and flavour. Old varieties or new hybrids are grown for this purpose, but most of them have not been tested yet in soilless systems.

Other plants : plants for pharmaceutical, nutraceutical, landscape uses

Medicinal plants (calendula, comfrey, etc.) can also be an interesting niche urban market, and so can plants used for industrial purposes such as tinctorial plants (chamomile, fenugreek, etc.). Rare plants on the market (vanilla, saffron, etc.) are grown by a few urban farmers. Finally, ornamental and landscape plants (on balconies, terraces or in small gardens) can be a good solution to target the urban gardener market. Edible flowers are also original products that should be taken into consideration.

DEFINITION OF THE ENVIRONMENT CONTROL SYSTEM

The reason why we use a greenhouse is to generate optimal growing conditions for the plants. Inside the greenhouse they are more protected from negative natural influences. To get to even more stable climate conditions in the greenhouse several technical possibilities have been introduced into the greenhouse business, which help to mitigate existing problems or finding solutions to grow plants in otherwise too harsh environments (early spring to grow early vegetable or fruits, etc.).

The difficult task designing a greenhouse is to find the optimal equipment and settings while staying within the boundaries of the project budget. In general, it can be advised to always focus on techniques which prevent a problem instead of getting rid of it. Additionally, passive systems, which use already existing energy flows are preferable.

It has to be mentioned that in a lot of cases of greenhouse construction projects the aspect of energy is neglected. But operating a greenhouse might become really energy intensive and therefore expensive. Reduced cost of the equipment can then lead to an expensive operation as well as technology failure.

INSULATION

Plants grow in limited temperature ranges and it is important for the RTG to offer controlled conditions.

One important aspect is the installation of permanent or removable insulation. Insulation consists of materials, which have a low heat conductivity. Therefore, heat loss is progressing slower than without the insulation. In general, it can be stated that the thicker the material the better the insulating properties.

Using insulation is an often-overlooked possibility to reduce heat loss and therefore mitigate the heating demand in a greenhouse since insulation materials are usually opaque and reduce the total light transmissions of the outer shell. But insulation is important to keep the heat inside of the greenhouse. It is necessary to find a good balance between light and insulated walls. Sidewalls can usually be equipped partially with insulation, walls facing north can be closed completely without losing any light.

There are several possibilities for insulating materials ranging from artificial (sandwich panels with PU (Polyurethane) , EPS (Expanded Polystyrene), mineral wool) or natural (wood wool, hemp, straw or cellulose). Using natural insulating materials leads to a reduced CO_2 impact, but comes along with a more complicated installation and often with higher cost. There are some transparent insulating materials available but usually either the insulating properties are not good enough to serve as a replacement, the transparency is quite low, or the price is too high to make the project economically feasible.

For the transparent openings double layered films or double skin sheets are available using traditional greenhouse materials or double-glazed coatings if glass is used.

Additionally, there heating screens are a possible solution. Here, an internally mounted screen is drawn out reducing the transmissivity heat losses. Such systems can also be installed for the side walls.

VENTILATION

One of the largest obstacles with operating a greenhouse is the overheating in summer. The easiest technically solution is to open up the greenhouse with vents. These are normally mounted at the highest point in the greenhouse. Heated air will rise and can escape through the ventilation openings. To make use of natural air movements it can also help to create flaps at the bottom side of the greenhouse to generate continuous flow of hot air escaping at the top while colder air gets in at the bottom. Depending on the rooftop situation and the style of the greenhouse, this very simple technique alone can be enough to achieve fitting growing conditions.

Next to natural or free ventilation it is possible to equip the greenhouse with forced ventilation systems, for example using fans to push in or suck out air. While it is a lot easier to control the forced ventilation also more energy is used, and the equipment is expensive.

It is important to mention that using ventilation also reduces the humidity in the air which gets transpired from the plants. This will lead to a loss of irrigation water to the environment.

SHADING SYSTEMS

Heat curtains and screens are a proven method of reducing heat gain in an RTG.

Furthermore, plants need warmth to grow on the one hand, on the other hand, too strong radiation leads to plant stress and reduced growing capabilities.

A simple solution is the installation of a shading screen which gets installed the same way as a heating screen. If a critical radiation threshold is overstepped the greenhouse control system automatically closes the screen. Thus, direct sunlight decreases, increasing the growing conditions for the plants and decreasing the necessity to cool the greenhouse.

Shading screens are normally made of a partially reflective and transmissivity material since it is not wanted to shut out sunlight completely. Some cultivation methods of certain plants need more controlled light. light deprivation system can be installed which offers complete darkness and should not be confused with a shading system. But in climates with intense sunlight over noon it is possible to use a light deprivation system to help the plants prevent overheating damage.

COOLING SYSTEMS

If either ventilation or shading was not enough to reduce the heat in the greenhouse, it is possible to use cooling methods.

First, the easiest and not very energy intensive method is to use adiabatic cooling. This technique uses the stored energy in the changes in the physical state of water to vapor, the same effect which cools the skin after leaving a swimming pool. Adiabatic cooling can be done with evaporation pads or misting devices. Evaporation pads are made from cardboard and are installed in the side or back walls of a greenhouse. The cardboard gets soaked with water and air is sucked through the fabric. The water evaporates and cooler but more humid air enters the greenhouse. Misting devices scatter water into very small droplets inside the greenhouse which evaporate quickly achieving the same effect. Adiabatic cooling devices have the disadvantage that they use a lot of water which gets lost with ventilation, also they only work in dry climate conditions. In comparison to chillers or cooling units adiabatic cooling has a lower energy demand.

Chillers use electrical energy to transfer heat to a thermal reservoir. In the case of a greenhouse this means that the heat from inside the greenhouse gets transferred to the outside air via heat exchangers. This process is energy intensive and the cooling units themselves are expensive which is why usually they are not used in horticulture.

Chillers can also be used for dehumidification. On the cold surfaces of the heat exchanger inside the greenhouse water condensates and can be collected. The water condensing heats up the heat exchanger with the reverse effect described before, leading to more energy demand for the cooling unit. In hot climates this can be used in combination with photovoltaics to prevent water scarcity while maintaining an energetically optimized operation.

SUPPLEMENTARY LIGHTING

Besides warmth, plants need enough light to grow. In winter or the transition periods in early mornings or late evenings there is not enough late to trigger plant growth.

Achieving better growing conditions can be done by using assimilation lights. Here, possibilities like modern LED techniques or plasma lamps are possible. In the greenhouse business sometimes high-pressure sodium lamps are used.

Generally, the energy demand is high using assimilation lights, which renders their usage uneconomic if the crop yield or the revenue is not high enough.

In addition, it has to be mentioned that rooftop greenhouses, especially in residential areas are bound to maintain a low light profile in the evening or at night. Without shading, using assimilation lights might be too intrusive for the surrounding areas.

ENERGY CONNECTION TO THE BUILDING

One of the key aspects of rooftop greenhouses is the connection between the greenhouse and the rooftop. In the support building, heating, ventilation and cooling are most probably already available and it can be possible to use already existing HVAC systems (Heating Ventilation Air Conditioning).

Implementing the greenhouse into already existing flows might help to increase the energy efficiency of the already installed systems :

- Reducing the return flow temperature of the heating system increases the efficiency of the boiler.
- The greenhouse can preheat the inlet air for the building ventilation (via heat exchanger)
- Waste heat from the building (chiller, bakery, restaurants etc.) can be used year-round for the heating of the greenhouse.
- Using the heat generated inside of the greenhouse to heat the support building can help both the greenhouse and the support building (greenhouse as solar collector).
- etc.

To reduce CO_2 emissions through rooftop greenhouses it is crucial that we find possible synergies. With that the combination of support building and greenhouse can achieve a better efficiency and increase the usage of available forces then each building separately.

CO_2 CAPTURE FROM THE BUILDING

Furthermore, especially in office buildings the air is enriched with CO_2 over the day. Connecting the exhaust air to the greenhouse creates the opportunity to fertilize the greenhouse with CO_2 enriched air which can be beneficial for plant growth.

PEST AND DISEASE MANAGEMENT (INTEGRATED BIOLOGICAL PROTECTION)

Before the cultivation process starts, pest and disease attacks need to be evaluated and anticipated by an agronomist. They will depend of crops selection, climate conditions, prophylaxis and other factors. Many techniques already exist to fight against pest and disease, like pests' capture (pheromones, light, etc.), host plants for auxiliary insects (attraction, feeding...), association of plants, etc. At this stage, a good agronomic expertise is necessary.

illustration of the integrated biological crop protection by using glue trap. Credits : ASTREDHOR

HORTICULTURAL PROCESSES

The team skill will depend of the technical intensity of the project as well as the social and pedagogical objectives. Horticultural activities are time consuming, especially during spring and summer seasons and it must be anticipated for the teamwork planning (work during the weekend, etc.). After all, harvesting and packaging process need to be perfectly foreseen. A specific area for storage, sorting, packaging activities must be design.

Horticultural practices that might be planned in this agricultural area are :

- preparation and sowing of seeds
- preparation of growing media
- preparation of the nutrient solution
- Installation of crops and growth tracking
- pruning and extraction of excess biomass
- harvesting, sorting and packaging
- etc.

EXPLOITATION

COMMUNICATION TIP

EXPLOITATION PHASE

ROOFTOP GREENHOUSES CLIMATE MANAGEMENT

MANAGEMENT OF RAINWATER FOR THE SUPPLY OF ROOFTOP GREENHOUSES

MANAGEMENT AND FARMING SYSTEMS OF ROOFTOP GREENHOUSES

TECHNICAL, ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF ROOFTOP GREENHOUSES

SOCIAL ASPECT

TECHNICAL, ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF ROOFTOP GREENHOUSES

By Karsten WILHELM (IfaS, DE), Ulrike KIRSCHNICK (IfaS, DE), Zaira Ambu (HS Trier/IfaS, DE), Nicolas ANCION (ULg, BE), Nicoleta SCHIOPU (CSTB, Fr)

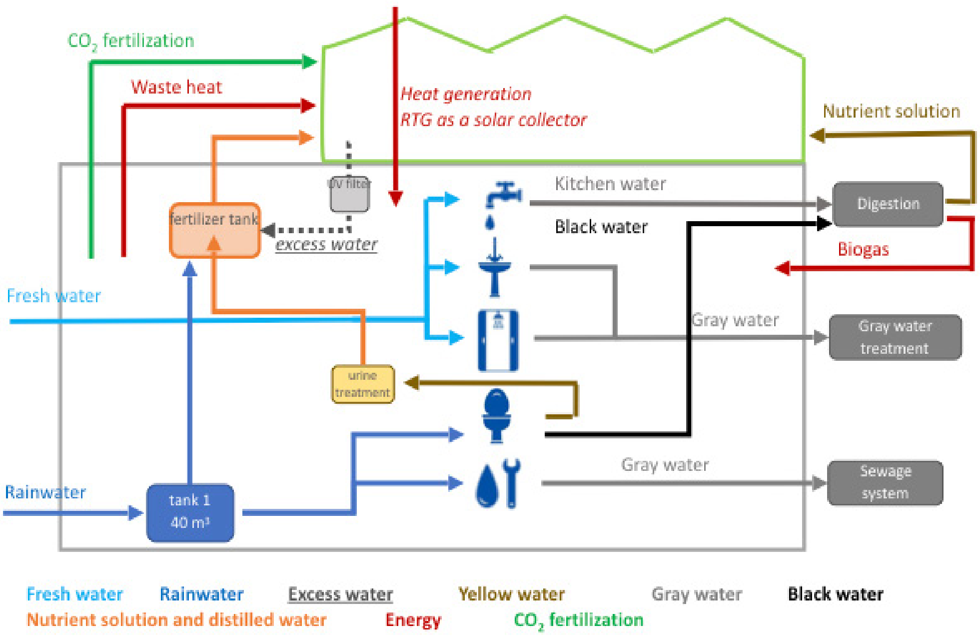
INTRODUCTION

Future cities need solutions to improve quality of life, reduce greenhouse gas (GHG) emissions, and adapt to climate change. A symbiosis between urban environment and agriculture production can help fight climate change and improve overall living conditions in cities. The GROOF project aims to reduce GHG emissions by creating a synergy between rooftop greenhouses (RTGs) and buildings. It reduces transportation emissions by creating local food production. This assessment of RTGs provides information on a symbiosis between greenhouses and buildings and the economic aspects of urban food production.

TECHNICAL ASSESSMENT OF RTGS IN THE GROOF PROJECT

The synergies between RTGs and buildings offer a wide range of potentials corresponding to environmental benefits quantifiable in terms of reduced gas emissions. These synergies and their relative flows are illustrated in the figure below to provide a legible view of interrelationships among systems diagrams.

See figure below : Symbiotic relationship between an RTG and a building in which waste streams are interrelated, and reciprocal exchanges of flows are optimised.



The GROOF project offers insights into the following CO_2 eq-mitigating synergies :

- Energy (using waste heat from the building or greenhouse)
- Using a PV system integrated in a greenhouse
- Water (using rainwater)
- CO_2 recovery from the building (derived from human activities)

This will be analysed and monitored in four pilot RTGs established in France, Belgium, Germany, and Luxemburg.

ENVIRONMENTAL ASSESSMENT

Life cycle assessment (LCA) was chosen as the suitable methodology to assess and demonstrate the potential mitigation of CO_2 emissions by RTGs in the different scenarios of the GROOF project in NWE. LCA is a useful tool to quantify environmental impacts of different kinds of systems (products, buildings, etc.) according to international standards (ISO 14 040 and 14 044). Methodological specifications of the LCA for the construction sector are given in European standards EN 15 804 and 15 978. The goal and scope of the LCA are in accordance with the objective given by the Interreg NWE funding program, i.e. to facilitate the implementation of low-carbon, energy, and climate protection strategies to reduce GHG emissions. The GROOF scenarios are compared with business-as-usual scenarios, considering the main contributors :

1. Products needed to build/renovate the building and the RTG
2. Energy consumption of the building and the RTG
3. Fertilisers for crop production in the RTG
4. Water consumptions of the building and the RTG
5. Land use change as an indicator of the space efficiency benefits of RTGs
6. Crop transportation from the RTG to the building (business-as-usual scenario : 150 km).

ECONOMIC ASSESSMENT OF RTGS

An assessment based on the life cycle costing (LCC) method is the following documents :

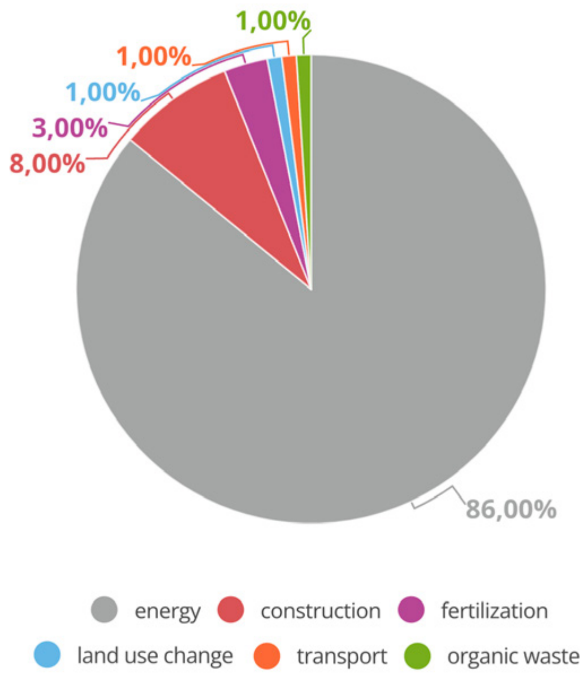
Ref. Hunkeler et al. (2008), Swarr et al. (2011) and ISO (2008) Ref. Hunkeler et al. (2008), Swarr et al. (2011) and ISO (2008)

Peña, A. and Rovira-Val, M. R. (2020) ‘A longitudinal literature review of life cycle costing applied to urban agriculture’, International Journal of Life Cycle Assessment. doi : 10.1007/s11367-020-01768-y.

CONCLUSIONS

Greenhouse production can be energy-intensive : this depends on the greenhouse design and crop species. We compared synergetic rooftop production with conventional production systems to calculate GHG emission savings. For this reason, we analysed the energy and material flows of different commercial greenhouse designs (from highly efficient to inefficient) and crop production systems (lettuce to tomato).

The analysis showed that the highest CO_2 emission saving can be achieved by combining energy efficiency measures and the use of renewable energies. The following figure shows the CO_2 emissions of a conventional tomato production system.



GHG emissions of the energy and material flows of conventional tomato production.

Based on these results, the reduction of GHG emissions is strictly related to the greenhouse system type, the symbiosis between the building and the RTG and the use of renewable materials and energies. Possible components of such a system are :

- recovering waste heat from the building and the greenhouse or using renewable thermal energy sources,
- sustainable construction materials : recycled or renewable raw materials,
- integrating a PV (photovoltaïc) system to use renewable energies.

Additional potentials include producing local fertiliser because efficient nutrient recovery is possible in urban buildings that host many users. For example, separate collection of urine can recover nutrients for fertilisation and reduce the fertiliser demand for the production system.

Overall, depending on each pilot scenario, it will be possible to save 10 to 20 t CO_2eq per m² * year within the GROOF project framework as compared to conventional production systems.

More detailed results will be available at the end of the project, based on fine-tuned modelling and monitoring over an 18-month period.

EXPLOITATION

COMMUNICATION TIP

EXPLOITATION PHASE

ROOFTOP GREENHOUSES CLIMATE MANAGEMENT

MANAGEMENT OF RAINWATER FOR THE SUPPLY OF ROOFTOP GREENHOUSES

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SOCIAL ASPECT

SOCIAL ASPECTS

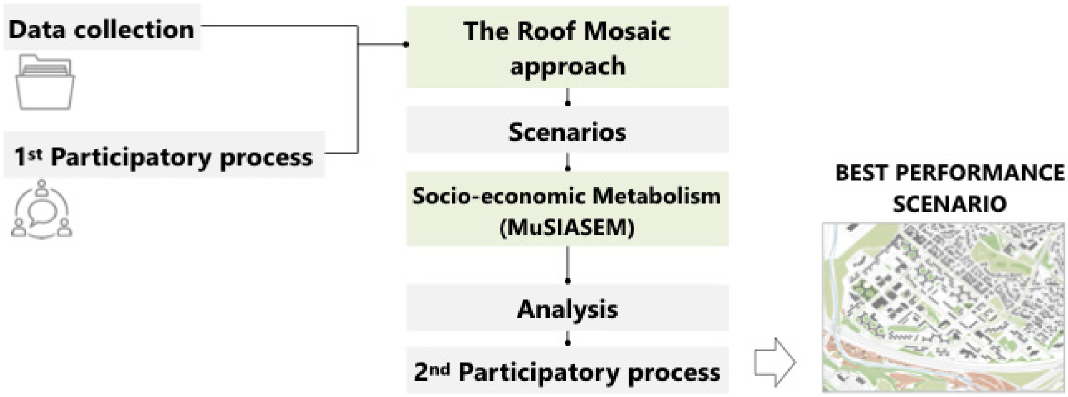
By Susana Toboso (UAB, Es), Xavier Gabarrell (UAB, Es), Gara Villalba (UAB, Es), Cristina Madrid (UAB, Es), Ramiro Gonzalez (UAB, Es), Caroline BINI (Groupe One, BE)

Perception of the product and the facility (neighbours, residents of nearby buildings)

1. Follow-up survey of different stakeholders, users, and residents nearby the greenhouse. Hydroponic or soilless crops are commonly used in this case because they easily adapt to rooftop constraints (e.g. the weight capacity of floors). However, the acceptance of the produces derived from this system is controversial because European laws do not consider them as ecological farming. Therefore, consumer acceptance of this kind of local food should be considered. See an example about the assessment of taste by potential consumers and their perception in this published paper. This paper seeks to answer two main questions, among others :

- How do consumers perceive the quality of the products grown in soilless rooftop farming systems ? and
- How do consumers perceive soilless production systems for roof-top farming ?

The complete survey included 27 open and closed questions and was structured into four sections.



Methodology to decide which systems to deploy on urban roof

2. General information : this section included closed questions (i.e., multiple choice questions) about the socio-economic profile of the participants – age, gender, level of schooling, profession, and income. These data were collected for statistical analysis purposes.

3. Perception of the product quality : this section consisted of closed questions that evaluated different aspects of the quality of the product, i.e., aspect, texture, size and flavour, and ripeness. The Likert scale method can be used for rating each aspect. This scale is a psychometric response scale primarily used in questionnaires to assess the subject's perception and usually proposes a 5-point scale (ordinal data), assigning a numerical value to each level. For example, 5 answers were proposed to the question "How do you rate the state of the tomato you have eaten ?" : "very good", "good", "acceptable", "bad" and "very bad".

4. Product sale : this section included closed and open questions about the motivations and preferences for purchasing food products from soilless cultivation systems from rooftop greenhouses (RTGs), including willingness to pay, preference for a type of packaging, preferred sales channel, regularity of purchase, and environmental information about the product. This third section was only proposed in the second campaign to collect tips about how business models should be focused.

5. Final comments : the survey ended with an open question referred to the food production and supply methods, i.e. "Do you want to add other comments or opinions" ?

SOCIAL INDICATORS

Different methodologies are available to calculate social indicators, some more complex than others. Therefore, it is recommendable to differentiate between two groups of installations :

1. Small rooftop greenhouses (RTGs) for self-sufficiency : short list of easy-to-measure indicators
2. Large commercial RTGs : social life cycle assessment (SLCA)

On the left : SLCA levels

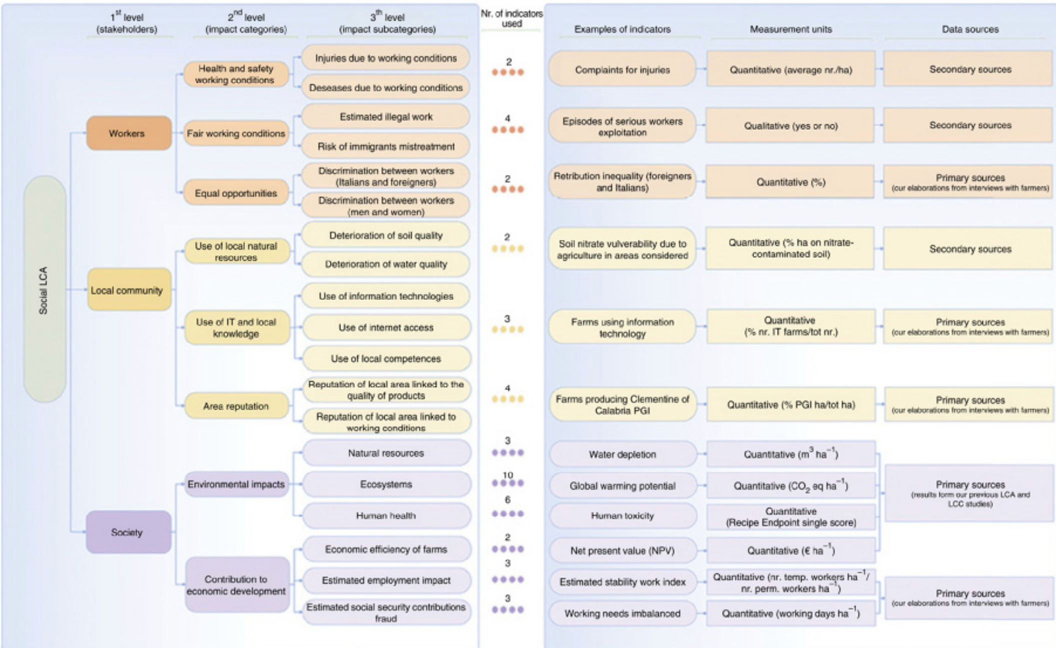
For small RTGs intended for self-sufficiency, a relevant list of social indicators will be advisable. These social indicators should be easy to measure and can be quantitative or qualitative. Therefore, an SLCA is not recommended because many data will be required, and they will be difficult to obtain. Moreover, it is advisable to decide about the social indicators that will be measured based on residents' interests during the participatory pre-project process with the residents.

Some of the proposed social indicators are :

- Coverage of residents' diet (in % and/or absolute values)
- Maintenance investment (hours/household/year) (Toboso-Chavero et al., 2020)
- Community engagement- Organisational support for community initiatives, using questionnaires/interviews) (Benoît-Norris et al., 2013)
- Local Employment (in % and/or absolute values) (UNEP/SETAC, 2013)
- Increase of wellbeing, using questionnaires/interviews (Ambrose et al., 2020)

For large commercial RTGs, an SLCA is better suited. This methodology aims to assess the social and socio-economic aspects of products along their life cycle. The SLCA guideline framework distinguishes five groups of stakeholders : workers, local community, society, consumers, and value chain actors. Next comes a second level including six impact categories : human rights, working conditions, health and safety, cultural heritage, governance, and socio-economic aspects, and then a third one including impact subcategories and social indicators (see figure below). SLCA studies usually target sector or company scales, or products produced in developing countries, with social conflicts or special interests.

Figure : Example of social indicators (Zamagni et al., 2015) (click to download)



Introduction
Preparation
Execution
Exploitation
Feedbaks
Pilot Projects
FAQ

FEEDBACKS

Case studies based on visits

THE FERTILECITY IN BARCELONA, OPERATED BY UAB (SPAIN)

THE NEW FARM IN DEN HAAG, OPERATED BY URBAN FARMERS (THE NETHERLANDS)

THE ABATTOIR IN ANDERLECHT, OPERATED BY BIGH (BELGIUM)

FERTILECITY IN BARCELONA, OPERATED BY UAB (SPAIN)

By Maeva Sabre (CSTB, Fr)

Pilot Id

The building was new, the 245-m² greenhouse was built in 2012-2013, and production started in 2014. UB was the architect and the founder.

The main purpose of the top floor greenhouse was research.

The main activities are plant production, visits, training, research, and vegetable (tomatoes, herbs) cultivation.

Business – value creation

The main activity of the greenhouse (and of the building too) is research. Because of this there is no specific business model as there would be in conventional farming targeting profitable production.

Construction

The building is 16 meters high, and composed of two basements, 3 floors, and an RTG. The height of the building including the greenhouse is 20 meters. The structure is made of reinforced concrete on pillars and post-tensioned slabs. The total roof surface is 1,180 m², with 245 m² dedicated to the greenhouse and 935 m² dedicated to other uses.

It was designed according to national standards, i.e. the Spanish construction code "Codigo técnico de la Edification" and other regulations of the public code and educational code. The roof was initially designed to receive a greenhouse

- **Permanent Load** : 2.5 kN/m²
- **Exploitation overload** : 4.5 kN/m²
- **Snow overload** : 0.4 kN/m²
- **Wind load** : 0.5 kN/m²

The roof covering is composed of an asphalt layer adhering to the concrete slab + an inverted insulation layer + a heavy protection made of 10 cm of a thick water-repellent concrete pavement.

The evacuation system is based on gravity, and rainwater is collected from the entire roof.

Other neighbouring roofs are connected to the rainwater harvesting system. In total, an area of about 1,900 m² is used for collecting rainwater. The capacity of the tank is 100 m³ with additional room, and 35 m³ for ultra-filtered water. This system reduces water consumption by 18%.

The greenhouse is 4 meters high.

The frame is made of steel. Facades are made of corrugated polycarbonate sheets whose opening and closing can be monitored for ventilation.

The connection to the greenhouse and to the exterior can be regulated through polyethylene film curtains that can be rolled up and down by an automated system.

Energy management

The building is an example of a fully integrated RTG. It produces heat, CO_2 and rainwater, i.e. ideal conditions for plant growth. The average temperatures are 16.5 °C in winter and 25.79 °C summer (2015 data).

Due to thermal inertia and waste heat, an additional heating system is not necessary, so that the integrated greenhouse recycles 341.93 kWh/m²·yr from the main building. This recycled energy amounts to CO_2 and cost savings (113.8 CO_2 (eq)/m²·yr and 19.63 €/m²·yr compared with an oil-heated freestanding greenhouse) (A. Nadal et al., 2017).

The vents are managed by an automatic control system. The CO_2-loaded waste air from working areas in the building is recirculated to the greenhouse for carbon fertilisation.

Greenhouse conditions and outdoor conditions are monitored. Based on this data, the heat demand of the greenhouse can be calculated. The heat itself is supplied by a geothermal system that reaches about 100 m into the ground. In the cold season, the greenhouse air is kept above a temperature of 14°C thanks to the connection to the building. This leads to energy savings of 390 kWh/m²*yr.

Finally, thermal screens are also used as energy savers.

Production

The greenhouse has a total surface of 245 m². However, only part of its surface is dedicated to crops. There is a 75-m² area for tomatoes and another 75-m² area for other crops with shorter growth cycles (leafy greens, spinach, chard, etc.).

It uses a hydroponic system with perlite as a growing media. The crops are irrigated with collected rainwater. The water is collected from the ICTA building (approx. 1,600 m²) and from the roof of the neighbouring EUREKA building (approx. 500 m²), and is accumulated in two tanks, a 100-m³ tank for irrigation water and another 35-m³ tank for ultra-filtered water.

The main activity of the greenhouse (and of the building too) is research. The harvested vegetables are shared among the building users or used in the common dining area.

Herb production runs all year round. Tomatoes are not cultivated during the coldest winter period. The tomato area produces 1,660 kg yearly.

These activities also generate waste :

- **300 kg** of plant biomass residues generated during the production season and at the end of it
- **30 kg** of growing media are lost in the cropping process
- **30 kg** of plastic waste.

FEEDBACKS

Case studies based on visits

THE FERTILECITY IN BARCELONA, OPERATED BY UAB (SPAIN)

THE NEW FARM IN DEN HAAG, OPERATED BY URBAN FARMERS (THE NETHERLANDS)

THE ABATTOIR IN ANDERLECHT, OPERATED BY BIGH (BELGIUM)

THE NEW FARM IN DEN HAAG, OPERATED BY URBAN FARMERS (THE NETHERLANDS)

By Maeva Sabre (CSTB, Fr)

Pilot Id

The building is a tall existing industrial building, the greenhouse was built directly on the roof in 2015, and production started in 2016. The building is in an industrial area close to the centre of **Den Haag**.

The building was formerly a Philips manufacture. It was abandoned, and Urban Farmer offered the city authorities of The Hague to study a project for its refurbishment and the implementation of a greenhouse on the roof and a fish production unit on the top floor.

Refurbishment work consisted of the reinforcement of the structure of the 5th floor, extension works above the flat roof of the 6th floor, and the construction of the greenhouse structure on the roof.

The "UF 002 De Schilde" greenhouse was installed at the top of an empty office block of the 1950's that once belonged to the Dutch telecommunications powerhouse Philips. It is located above an abandoned reception desk and six floors of vacant office space. The greenhouse is located on the highest level on the roof, but Urban Farmer activity is also on the 6th floor with a welcome desk, a shop, a terrace, and fish production units.

The building is a brick-and-glass seven-floor building. It was built as a television and telephone factory for Philips in the 1950's by the modernist architect Dirk Roosenburg. It has about 12,400 m² of total floor space, largely abandoned but too solid and expensive to knock down.

Key numbers

- rooftop 1,200 m²,
- greenhouse 700 m²,
- aquaponics 300 m²

Architect : Space & matter; founder : Andreas Graber

Main activities : plant and fish production, events, visits, shops, etc., with 45 tons of vegetables (leafy greens, tomatoes, eggplant, basil) and 19 tons of fish (Tilapia).

Business - value creation

Energy costs are variable depending on the season of the year. These costs are 3,000 €/month in the summer months, while they rise to 15,000 €/month in the cold months.

NB : information was lacking about this section during and after the visit. For example, the business model was not provided, it usually remains confidential.

Construction

Access to the greenhouse is safe by the lift and stairs. The roof perimeter is enclosed by a 2-meter high wood frame. Inside the greenhouse, the lowest part of the facade is made of rigid sandwich panels. On the 6th floor, the existing terrace was not modified (the safety barrier seems to be convenient for use).

The existing rooftop was kept. It was originally made of hard concrete covered with bituminous waterproofing material. One part of the greenhouse structure was built directly on the roof.

An extension of the existing roof was built above the existing terrace on the 6th floor. The additional structure was built in concrete. The new concrete slab is 30 cm thick on average. Six new pillars along the existing 6th floor terrace have been added.

Access to the greenhouse is possible both by the main lift up to the 6th floor and by a staircase to the roof, and access to both is possible by a new steel staircase. The total load of the greenhouse is distributed to the existing bearing walls and beams. Single-glazed tempered glass had been used for the facade. The penetration of the concrete slab of the greenhouse roof are scarce, with only one area where the water and heating ducts can be passed.

The greenhouse is divided in two zones.

- The first one is directly implemented on the existing waterproofing membrane. Farming equipment is light-frame steel, rolling on a free rail on the floor. The RTG structure is made of steel and fixed along the structural concrete wall.
- The second one is built on an additional concrete slab. Farming equipment is hanging from the steel frame of the roof. Trolley rails are anchored on the concrete slab. The rail system is supplemented with heating pipes.

There is a 30 cm gap between the two zones of the greenhouse. A sign of failure is visible along the side of the concrete floor, probably due to differences in thermal dilation.

The facades are built with sandwich panels, and single-glazed tempered glass. The roof is made of single-glazed tempered glass.

The heating pipes are hooked to the vertical steel frame along the greenhouse perimeter.

There is no water outlet located in the greenhouse. All rainwater outlets are located outside, and water from surfaces (the roof and facades) is harvested. The pipe that brings water to the RTG is in the irrigation room, in which the PRIVA control system is installed. This software program manages the water quality parameters : pH 6 to 6.5 and conductivity. The entrance area contains a calcium tank, a sulphuric acid tank, etc.

Another room dedicated to fish food storage is temperature and humidity conditioned.

A concrete layer was laid on the existing floor. A siphon system was installed to manage water collection. There is no flooring on the concrete, no tiling, no resin. The slope of the concrete slab was studied; it seemed that after the first filling of the tank, the structure did bear this huge load but stabilised to a new slope after loading. We did not see any trace of stagnant water. Also, the water collection system runs correctly.

Tanks are made of plastic. There are 20 tanks of 4.5 m^3 and 10 tanks of 3 m^3 for a total of 120 m^3. Their feet are made of stainless steel, each foot is 30 mm long x 30 mm wide. They are directly installed on the concrete floor. The pipes run on the floor. Pumps are located close to the water treatment tank.

NB : data were lacking about this section during and after the visit, e.g. about climate impacts (wind, snow, rain) because of the height of the building : how the greenhouse structure resists and what are the specific properties required from the materials (glass, steel...) or whether all parameters are controlled by PRIVA. It should be very useful for the project to be able to explain or compare the initial design hypotheses (wind speed, solar radiation, temperature) with the real data collected by the instruments (sensor, anemometer, thermometer, etc.).

Energy management

It is interesting to know that external climate conditions (average monthly high and low temperatures) in Den Haag are monitored to know the potential energy needs.

The greenhouse type is a standard Venlo greenhouse. Adjusted to a high altitude (>30m), the glass shell is double-glazed and the greenhouse structure itself has been reinforced. However, the divides between the different greenhouses (visitors' greenhouse, fruit greenhouse, and salad greenhouse) are made of single-glazed glass.

No energy advice was searched for while initially working on the concept, and apart from economic reasons, the need to reduce energy requirements was not a goal. Consequently, there is no use of existing energy flows and no connection between the greenhouse and the structure below. Since the building is still not fully occupied, gaining efficient synergy effects is not possible.

The RTG uses a gas boiler and heating is distributed by water pipes. It does not have a cooling system besides natural ventilation and shading. However, it has a movable shading screen, which can help to reduce heat losses although it is porous and air permeable.

The greenhouse is ventilated using traditional Venlo-type ventilators (roof ventilators, no side ventilators). Given the fact that the RTG is located on top of the 5th floor of the building, the wind regime is stronger than at the ground level, so vents should be enough to guarantee good growing conditions even in the hottest days. Nevertheless, UF mentioned that the vents were not opened completely to avoid pests.

Another cause of energy consumption is the artificial growing lights. These are sodium vapour lamps of 400 W each for the leafy-green greenhouse and 600 W each for the fruit greenhouse.

There is no CO_2 enrichment system in the RTG. The CO_2 from the fish room (which has a CO_2 concentration of 1,400 ppm) cannot be used because it is too humid, particularly in winter.

Potential improvements

- Using F-Clean film instead of double-glazed windows to reduce the weight load of the greenhouse could lead to a different and cheaper support structure.
- Installing thermal screens on the side walls, front walls and over the crops is a well-known technique that is not used among the UF De Schilde facilities. Once construction works are over, installing such screens is more difficult and expensive. Thermal screens would help to reduce energy consumption and associated CO_2 emissions.
- Diffuse glass provides better light use efficiency than clear glass (8% increase in productivity have been reported in The Netherlands). Clear glass is more attractive visually, so perhaps a combination of clear glass on the front and side walls with diffuse glass on the roof would have been advisable. Also, antireflective treatment and low-emissivity treatment on the glass sides are generally recommended. Once the greenhouse has been built, replacing the cladding materials is unjustified, but this is something to be considered for future designs. The best covering material can reach more productivity with equal or lower energy inputs, so it helps to reduce CO_2 emissions per unit of produce.
- Artificial CO_2 enrichment is strongly recommended. It is not an expensive technique; it can be retrofitted to existing greenhouses and it boosts productivity.
- Integration to the building is not complete in terms of energy and CO_2 exchanges. Only water from the fish tanks, which is rich in nutrients, is interchanged from the building to the RTG. To reduce CO_2 emissions by the RTG, perhaps the RTG can benefit from waste heat from the building. Once the RTG is constructed it is not easy to use potential sources of waste heat produced in the building, but this point should be taken into account for future RTG designs.

NB : data were lacking about this section during and after the visit, e.g. the average heating consumption (kWh/year), the average electric consumption (kWh/year). Is the double-glazed glass anti-reflective glass ? Does it have a low emissivity treatment in one of the internal glass sides ? The GROOF experts observed that the RTG used more energy than conventional ground greenhouses, probably due to the different wind regime. Wind speed increases as height increases, and in turn energy losses by convection are higher. Besides, the RTG had no light screens, which are mandatory in the Netherlands to avoid light pollution.

Production

The RTG is divided into three major areas :

- the leafy green greenhouse (300 m²) is devoted to microgreens and leafy vegetables
- the fruit greenhouse (750 m²) where tomatoes, peppers, cucumbers, and eggplants are produced
- a shared service area, a visitors' hall, etc. In total, the glass-covered area is 1,200 m²

A nursery tank shelters the young fish for several weeks until they are sufficiently mature. Then, they are transferred to the bigger tanks to stay there until harvested. The operation mode to kill the fish is based on an electrical discharge in the specific tank. Fish are processed in a room directly at The New Farm and delivered to a processing company that cuts the fillets and sends them back to The New Farmer to be packed.

The fish tanks were initially filled with local tap water. The water from fish production is used to fertilise the plants in the greenhouse. A treatment tank based on bio-chips lowers nitrate levels and oxygenates the water. UV treatment neutralises micro-organisms. A CO_2 tower captures CO_2 emissions. The purified water is sent to the greenhouse once every two weeks. Additives (calcium, sulphuric acid, etc.) can be added to the water. In case of insufficient water capacity, tap water is added to the fish tank. No tap water is used directly to irrigate the plants.

The plants are cultivated manually; vegetables are picked, placed in plastic boxes and directly carried to the shop on the 6th floor. Organic waste is regularly collected and directly carried to the ground floor. Vegetables are grown on trapezoidal rock wool growing media. The tomato branches are very long and strong, 5 to 10 meters each on average.

NB : One of the biggest RTGs in Europe went bankrupt in July 2018. Although the project was set up by experienced urban growers, why did it shut down so quickly ? What are the main reasons for this unexpected bankruptcy ?

A dedicated report has been written by GROOF partners on the reasons.

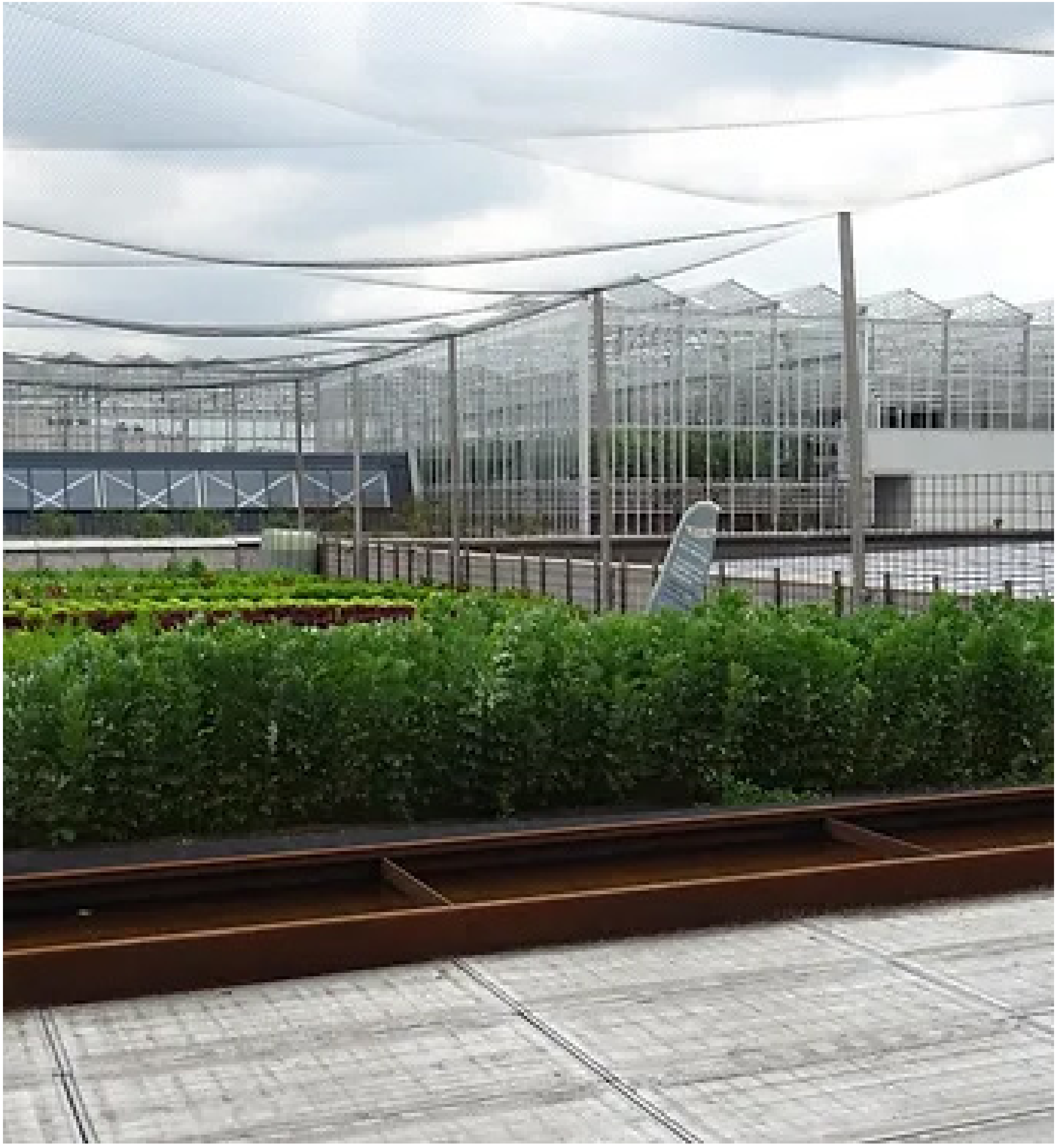
FEEDBACKS

Case studies based on visits

THE FERTILECITY IN BARCELONA, OPERATED BY UAB (SPAIN)

THE NEW FARM IN DEN HAAG, OPERATED BY URBAN FARMERS (THE NETHERLANDS)

THE ABATTOIR IN ANDERLECHT, OPERATED BY BIGH (BELGIUM)



THE ABATTOIR IN ANDERLECHT, OPERATED BY BIGH (BELGIUM)

By Maeva Sabre (CSTB, Fr)

Pilot Id

The building was an existing industrial building. The greenhouse was built in 2016-2017, and production started in 2018.

BIGH was founded in 2015, inspired by Steven Beckers, Cradle-to-Cradle accredited architect and co-founder of Lateral Thinking Factory Consultancy that has been supporting the implementation of circular economy in the real estate sector.

After conducting different studies in 2015 for the Brussels-Capital Region on the potential of urban farming, Lateral Thinking Factory Consultancy received many requests for finding operators. They failed, so they developed their own technical support along with ECF Farm systems, a commercial business model based on aquaponics integrated to buildings where buildings support agriculture and vice versa.

In 2016, enthusiastic financial partners and technical and commercial collaborators gathered to develop the BIGH model to build the first farm of the BIGH farm network : the Ferme Abattoir.

On January 2018, following 4 months of design and permit filings supported by ORG architects + 7 months of construction work, the Ferme Abattoir was ready for phased operations.

At the end of April 2018, the farm opened officially and became accessible to the public on demand, while first products were commercialised in the Brussels-Capital region from May 2018.

Key numbers

- 12,000 m² rooftop
- Greenhouse 1,400 m²
- Aquaponics 500 m²
- Outside garden 2,000 m²

Architect : Steven Beckers; founder : BIGH; building owners : FOODMET.

BIGH is the main contractor of the greenhouse and rents the roof that belongs to FOODMET.

Main activities : plant and fish production, visits, training sessions about vegetable (tomatoes, herbs) and fish (bar) farming.

Business – value creation

It is estimated that the electricity demand is about 260,000 kWhel/yr (50,000 kWhel/yr for LED, 210,000 kWhel/yr for the remaining appliances).

The multiple objectives of the Ferme Abattoir are to relocate production in the city, reduce energy consumption and CO_2 emission, reduce production costs.

The stakeholders of the project were the local authorities (i.e. the city of Brussels), the founder of BIGH (Steven Beckers), the CEO (Franck Goes).

The capital outlay was around 2.7 million euros; monthly fixed costs and monthly variable costs were not provided.

Construction

The site of the Abattoir in Anderlecht is a significant example of industrial architecture of the 19th century. The building on which the RTG was built is the most recent one on site.

This building is dedicated to the "Foodmet", a professional market-place for cash-and-carry of foods, etc. The roof was designed to receive a traditional garden (i.e. with natural soil) and was also solid enough to receive the resulting overload. So, why not a greenhouse structure ?! The urban farming project started in 2015 with a first engineering study. To comply with the initial idea, an outdoor roof garden was designed to produce vegetables, fruit, etc.

The roof layout also includes three parts :

- 2,000 m² for a two-floor greenhouse
- 2,000 m² for aquaponics
- 2,000 m² for an outdoor garden
- the rest of the roof for pedestrian access or a technical area, and an office
- construction lasted two years (2016 and 2017).

The host building is a slaughterhouse (abattoir) built in a heavy-weight construction type dominated by concrete elements. It was built in 2012. The rooftop is partially occupied by skylights and a few annexes.

The northern part of the roof is now occupied by PV panels operated by the host building owner. There is a permanent cooling demand for meat conservation, that makes an adequate waste heat source.

The roof would not have born the loads of the rooftop farm without reinforcements and static measures. There is no insulation in the roof, but the following layers :

- 60 cm of reinforced concrete
- 5 - 20 cm of lightweight concrete
- Roofing/waterproof sealing < 1 cm.

The heavy-weight construction offers thermal mass and adequate insulation properties. The structure was reinforced to bear the loads of different zones (600, 800 or 1,200 kg/m²). The reinforcement measures also transfer the greenhouse load to the substructure. A new concrete slab was made to correct the slope of the existing roof and to protect the waterproofing membrane.

The entire perimeter of the greenhouse was covered with a Derbigum Derbipure membrane characterised by an ecological composition and a white appearance. The green roof system was installed directly on the existing membrane, with

- a drainage layer
- a filter layer
- a soil layer.

There was no insulation on the existing roof, and no new insulation layer was added. Water outlets are a siphonic system. No modification was made. The transparent surfaces were made of single-glazed glass. Tempered glass was installed on the lowest part of the facade and on the greenhouse roof, and non-tempered glass on the rest of the facade. The ventilation system is on the greenhouse roof and operated with a mechanical opening system. The building is listed in the Industrial category and complies with local and national fire regulations.

The greenhouse area is about 1,300 m² and has only been used for tomatoes and herbs so far.

The greenhouse is cleared and cleaned in December. Thus, there is an 11-month growing period. The fish tanks are in separate rooms below the herb-growing area of the greenhouse. In total, 117 m³ of water are devoted to aquaculture.

Rooms for technical installations and offices are in a building next to the greenhouse and aquaculture area. They are built with recycled used containers. The roof garden is on the eastern part of the roof. It can be irrigated by aquaponics water.

The Venlo-type greenhouse is 7.6 m tall (from the floor to the roof ridge), gutter height is about 6.9 m. It is coated with single-glazed tempered glass. Vents are located on the roof. Energy screens are installed at gutter height, but there is no shading device. The main axis is oriented north-east to south-west.

The growing systems are fixed to the roof, so most of the loads are distributed to the outdoor elements of the greenhouse. Additional steel pillars inside the greenhouse secure the distribution of the load to the perimeter, which stands on reinforced structures of the host building rooftop.

The cultivation system is based on baskets suspended on a line. This way, the whole growing media and vegetable loads are mounted on the greenhouse structure. Only the heating system is fixed to the floor. The aquaponics system is placed directly on the floor.

Technical rooms are located along a corridor that separates the greenhouse from the fish production room. The outer wall is made of concrete; the partition wall is made of wood. Office containers are also directly on the bearing beams of the host building structure.

Three types of water are used to compensate for losses : rainwater, tap water and well water. Aquaponics is supplied with well water. There are 3 tanks of 35 cubic metres each, for a total of 105 cubic metres (temperature 24°C). Water must be heated from 10 - 12°C to 24°C. Losses are estimated to be approximately 5% of the total volume per day (6 to 8 m³/d). The water network is made of PE or PVC pipes, depending on the shape and installation.

Energy management

The greenhouse is a Venlo type structure with higher-than-usual structures (7.6 m). It was built with single-glazed windows, with the row closest to the ground made of tempered glass. For information, FOODMET had installed a photovoltaic system on another roof of the building.

All possibilities of reducing energy consumption were investigated based on recent standards or best practices, and no special energy advice was provided during the planning phase.

The greenhouse is heated, but not cooled, and there is little mechanical ventilation.

The host building has a steady cooling demand creating waste heat which is utilised to heat the greenhouse with a 140-kW heat pump. This constant flow at 15 °C on the primary side of the heat pump leads to a COP of about 5-6. The heat pump operates up to a water heat temperature of 60 °C.

In case of peak loads, the greenhouse is supplied by two gas boilers with a capacity of 100 kW each. In case of redundancy, the heating loop of the host building can be tapped. It is planned in such a way that the growing phase is interrupted each December for the interior to be cleaned and the growing systems to be adjusted. The total heating load was estimated to be about 380 kW (To= -5 °C, Ti = 20°C; 15 °C, ΔTwater= 12 K).

It is estimated that the annual heating demand is about 600,000 to 700,000 kWh (tomatoes 250,000 kWh/yr, herbs 150,000 kWh/yr., fish 270,000 kWh/yr). The estimation is based on a specific heating demand of 300 kWh/(m^2yr) for the tomato area and 260 kWh/(m^2yr) for the herb area.

There are 3 storage fridges cooled to 7-11 °C (plants) and 0-3 °C (fish); they are not used for waste heat recovery.

In terms of electricity, the farm needs a connection power of 290 kW (including 60 kW for LEDs) in total. Consumers are the heat pump, fans, pumps, the chiller, lighting, growing lights (LEDs).

The greenhouse itself is equipped with few energy screens at its top and some of the waste source of CO_2 is used, but the effect is not measured.

Here are examples of measures that could be retrofitted : the growing concept could be adjusted to operate at lower temperatures in winter and transition periods. Thus, leafy greens could be an option. This must be tuned within the aquaponics system. A shading system could be installed to reduce solar influx in summer. Measures that cannot be retrofitted could be using F-Clean film instead of glazing to reduce the weight load of the greenhouse and could also lead to a different and cheaper bearing structure. In addition, double-layer ETFE constructions have much better insulation properties. Double glazing could be used instead of single glazing. In this climate zone, losses in solar heat gains should be more than compensated for by the reduction of heat transmission

Production

Aquaponics greenhouse farms are located on unexploited commercial rooftops or land in urban or suburban environments. The farms are closely linked to the operation fluxes of the buildings.

High-tech production is integrated and fully transparent. A circular economy policy and zero waste of fresh natural vegetables, fruit and fish benefit from the fatal energy and CO_2 from the building's systems.

Fish and vegetable production goes on throughout the year. Two months are required for the maintenance of the tomato production area (November and December).

After the construction works, a certain period of time is required before production to adjust the aquaponic systems : regulate water quality, growing media composition, etc. to adapt to the fish and tomatoes that BIGH want to produce.

Production started in March 2018. Crops are tomatoes, herbs (basil, coriander, parsley, etc.). The expected greenhouse life cycle is 10 to 15 years.

Five people are employed daily to manage the activities of the Ferme Abattoir (visits, crops, packaging, etc.).

People involved in the project come from all over Europe (including France and Belgium). They get skills in biology, aquaculture, agronomy, horticulture, marketing, architecture, etc.

The Ferme Abattoir is also an attractive place for trainees.

Building Integrated Green Houses Holding SCA (BIGH holding SCA), the developer and operator of aquaponics urban farms, is raising funds to close a financing round aimed at developing its network of urban aquaponics greenhouse farms in Belgium and abroad.

PILOT PROJECTS

Feedbacks from Pilots developed within the framework of the GROOF project

SERR'URE, OPERATED BY UNIVERSITY OF LIÈGE (GEMBLOUX, BELGIUM)

By Jimmy Bin (ULiège, BE), Nicolas Ancion (ULiège, BE), Florent Scattareggia (ULiège, BE) et Haïssam Jijakli (ULiège, BE)

Pilot Id

The Research Centre in Urban farming of Liège University is developing a 198-m² (5.5 * 36 m) RTG in its Gembloux centre (Belgium). The greenhouse is inserted on the rooftop of a modern building of the agriculture faculty of Liège University – Gembloux Agro-Bio Tech faculty.

The Centre of Research in Urban Agriculture (C-RAU) is dedicated to the development and analysis of production systems and tools for farming adapted to urban and peri-urban environments. This includes both low-tech and high-tech approaches, such as SPIN (small plot intensive farming), agroforestry, permaculture, bioponics, aquaponics, rooftop farming and indoor cultivation. Therefore, the RTG will complete an ecosystem of research infrastructures, including experimental fields, aquaponics systems and container systems.

The RTG will be dedicated to research associated with the production systems adapted to rooftop farming at technical, scientific and economic levels. Besides, the greenhouse will also host educational activities and demonstrations of innovative plant production systems.

Business – value creation

The aim of the greenhouse is to reinforce the research infrastructures of the C-RAU of Liège University.

The economic model of a research centre is mainly based on public funding. Public financers generally evaluate the project based on the experience of the research centre and its ability to carry out research. Research greenhouses will enable the C-RAU to gather more experience and to host future experiments. In fine, this will open onto new types of funding for the research centre.

The Centre of Research in Urban Agriculture will sell its expertise to private companies. The greenhouse will be used to carry out experiments for external companies, e.g., evaluating production systems, fertilisers, or other types of products.

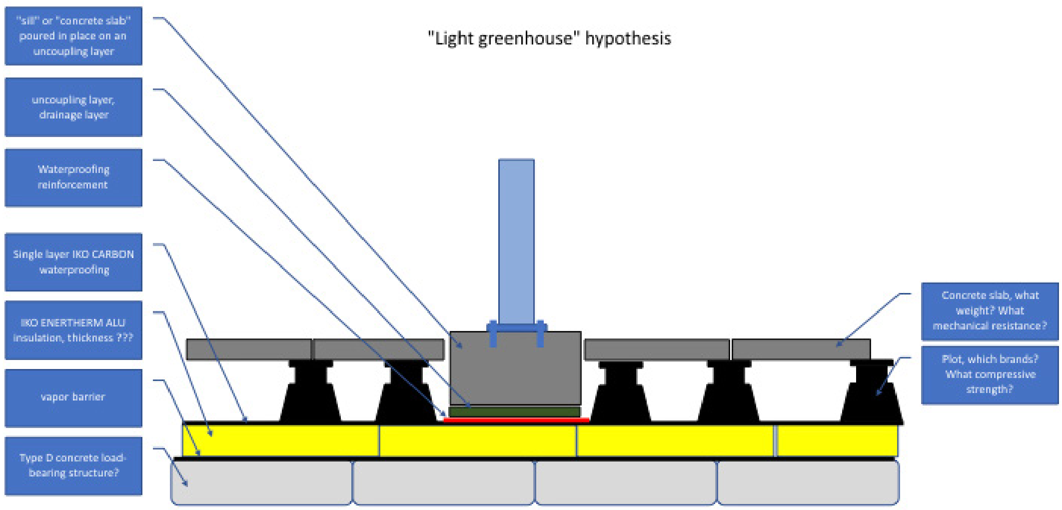
Construction

The TERRA building was designed to host urban farming activities. The roof has a high bearing capacity (4.5 KN/m²). Nevertheless, although the building can accept high loads, it cannot withstand lifting forces, such as the forces exerted by the wind on the greenhouse. Therefore, the greenhouse structure needs to be heavy enough to avoid any lifting force. This implies that even with the heaviest greenhouse material present on the market (safety glass), the greenhouse needs to be loaded.

The roof is covered by a 20 cm insulation layer made of polyisocyanurate foam and a waterproofing layer made of plastomer (APP) bitumen. These materials can handle relatively high pressures : a long-term pressure of 60 KN/m² results in a 1 mm deformation of the insulation layer. Insulation and waterproofing resistance are not a limiting factor in the construction of the greenhouse. Besides, the anchoring of the greenhouse in the building would require drilling through the insulation and waterproofing layer. This is quite expensive and raises questions as to insurance. Therefore, the greenhouse will not be anchored in the building, but simply laid down on the roof.

The greenhouse structure will be based on pillars with aluminium profiles spaced out every 6 m, which is the standard distance in greenhouse construction. These pillars will be inserted into a concrete structure laid down on the roof. The maximum forces exerted by the pillars on the concrete structure will range from -6 to 24 KN.

Construction itself is a major challenge of the project. The machine required to build the greenhouse, lift the structure and covering material is too heavy for the roof. Therefore, the greenhouse builder cannot work with standard lifting machines and will assemble the greenhouse manually with scaffolding. This will increase the cost of the greenhouse.



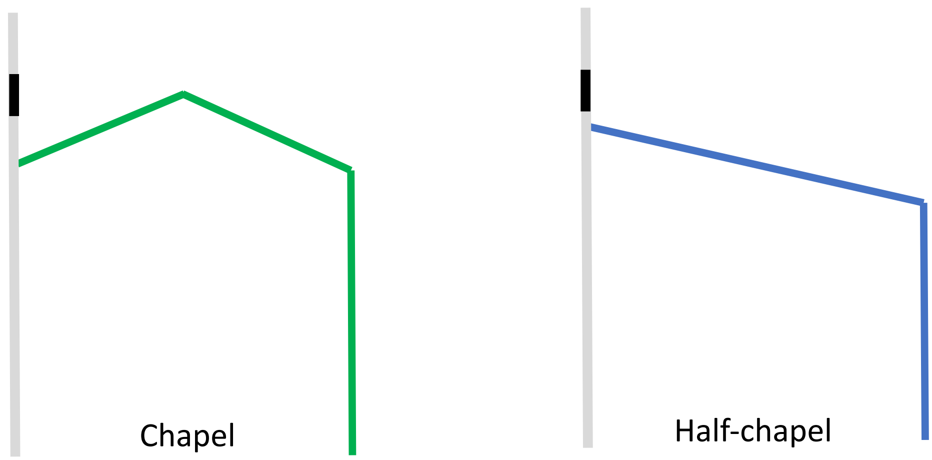
Energy management

The TERRA building is a recent building with modern energy management. This includes efficient insulation, ventilation, heating, and cooling systems. Moreover, the building has a technical hall dedicated to research on industrial food processing systems such as bakeries and refineries. All these devices produce heat, so that the hall needs to be actively cooled and ventilated all year long.

Due to the good insulation of the building, the greenhouse will not provide additive insulation to it. Therefore, the greenhouse will not recover heat from the building through the walls. The most obvious way to recover heat from the building would have been to use the air evacuated by the ventilation system, but the air outlet of the building is too far from the greenhouse. Carrying this air from the outlet to the greenhouse would not make sense from an energy point of view. The issue of proximity would have been easily corrected if it had been pointed out before the building was designed.

This project will increase the energy efficiency of the building and greenhouse by using the heat from the cooling system of the building to preheat the water going into the heating system of the building.

The shape of the greenhouse was also adapted to the building to increase its energy efficiency. The most popular greenhouse design is the chapel (see picture). This design is very efficient for large greenhouses. Nevertheless, in the case of a greenhouse standing against a wall fully exposed south, a half-chapel design increases energy capture by the greenhouse. In the case of the TERRA greenhouse, a half-chapel greenhouse will save 13% of heating energy compared to a chapel greenhouse.



Production

The main compartment of the greenhouse will be 24 m long and 5.5 m wide. It is dedicated to research on production systems adapted to rooftop farming in NWE. The greenhouse is designed to carry out experiments on the vegetables traditionally grown in the region and on plants producing medicinal molecules. This includes leafy greens (lettuce, chard, leek, etc.), herbs (basil, coriander, mint, etc.), fruit vegetables (tomato, pepper, eggplant, etc.) and medicinal plants.

The objective of the greenhouse influences its design in two ways. Firstly, the greenhouse needs to produce a climate adapted to all these species all year long (cool in summer to grow leafy greens, hot and luminous in winter to grow fruit vegetables). Secondly, the climate (temperature, light) should be the same in all parts of the greenhouse to comply with the requirements of research.

The needs for modularity, accuracy, and an even climate control in this research greenhouse will result in devices that are generally not required in a production greenhouse. The greenhouse will be coated in double glazing for efficient insulation, equipped with energy screens, heating systems, cooling systems (fog) and artificial lighting.

The research carried out in the greenhouse will be associated with the use of bio-sourced fertilisers. The facilities will allow for the testing of different fertilisers simultaneously. Therefore, the RTG will be equipped with a set of 10 NFT tables. Each NFT table will consist of five gutters providing the same fertiliser solution.

The greenhouse will also include a 5.5 m wide and 6 m long demonstration compartment. This compartment will host innovative production systems such as hydroponics towers to give feedback to the manufacturers, train university students and present these systems to the public.

PILOT PROJECTS

Feedbacks from Pilots developed within the framework of the GROOF project

FRESH, OPERATED BY IFSB (BETTEMBOURG, LUXEMBOURG)

By Marcel Deravet (IFSB, LU)

Pilot Id

FRESH is the Luxembourgish pilot project that has been installed on the roof of the existing restaurant extension of the Institut de Formation Sectoriel du Bâtiment (IFSB).

The IFSB is a training centre for the construction sector, notably sustainable construction, machinery, management, occupational safety and health, and the environment. The institute's stated objective is to position itself as the expert centre for sustainable construction in Luxembourg and neighbouring countries (France, Germany, Belgium).

The IFSB develops services to meet and anticipate the needs of construction companies in Luxembourg. Its goal also includes being a Grand Ducal showcase for the construction sector and promotion of innovative projects. Urban farming is part of the future of construction. Therefore, the IFSB and the Conseil pour le Développement Economique de la Construction (CDEC) participated in the drafting of the national strategy presented by the government of Luxembourg.

Luxembourg is a country where real estate develops very fast but cannot meet the needs related to demographic pressure. In this context, the IFSB saw an opportunity to develop a tool for the construction sector. The objective is to anticipate the needs of cities in the future, particularly in relation to food needs. This is where RTGs enter the scene.

The greenhouse cover around 380 m² on top of the IFSB restaurant. It is located near the training site, and the plants grown in it are in part served directly in the restaurant below. The project objective is to integrate a food production greenhouse on top of a restaurant. Raising people's awareness of what they eat will involve reconnecting them with food production. Popular and appreciated products such as tomatoes will be prioritised to meet the needs of the restaurant.

To strengthen the link between vegetable production and vegetable use in restaurants, a corridor around the greenhouse will allow visitors to view the production area without disturbing operational activities.

Finally, the connection to the building for CO_2 and heat recovery will make sense for the building sector. CO_2 recovery is an upcoming challenge for this sector in Luxembourg.

Business - value creation

The objective of the IFSB and FRESH is to develop a pilot and a proof of concept that such projects can be financially sound. Future consumers are expected to be (in a first phase) IFSB trainees and employees. The rest of the production should be sold in a short supply chain. Financial balance should be achieved by diversifying activities in collaboration with the future operator.

The fault in this reasoning could be the planning of a profitable production although the greenhouse area is relatively small. Therefore, it will be necessary to capitalise knowledge on all future achievements in Luxembourg and elsewhere. Nevertheless, fresh fruit and vegetable production – fully dedicated to local needs – will remain a very positive factor.

On the other hand, CO_2 is becoming a cost factor for the building sector. Luxembourg's government is currently planning to tax CO_2 emissions from buildings. This could be a valuable selling point for future promoters willing to find solutions for a better environment.

This other goal will be to emphasize that the CO_2 footprint of buildings can be lowered by making the construction and farming sectors work together.

The IFSB will provide an example of the construction of an efficient greenhouse that complies with the principles of circular economy. The life cycle and future dismantling of the RTG will be optimised, as well as upcycling of the materials.

Another target is to establish a link between the education and construction sectors to anticipate the country's needs – CO_2 management, food resilience, education, training, etc.

The greenhouse will not only be used to produce vegetables, but above all to exploit possible synergies with the restaurant below (CO_2, energy, social interactions, etc.).

With this project, the IFSB will offer training courses for people involved in the construction and farming sectors.

Construction

The construction of the restaurant and the greenhouse on its roof will comply with the principles of circular economy. A large part of the structure will be simple and robust, while allowing for simple future dismantling. Following this simple design logic, a metal frame and glass walls will be used. These materials are very easily reusable and recyclable. The principle of simple vertical load-bearing elements with fillings in-between allows fast construction, easy modifications, and low-cost renovation if necessary.

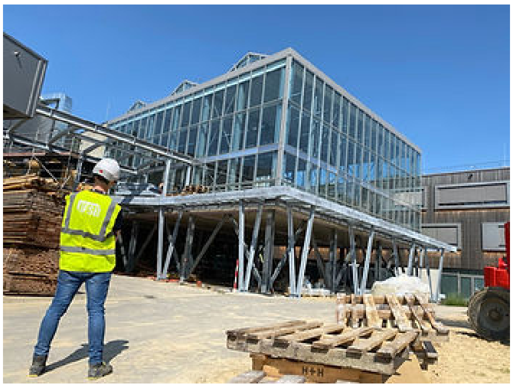
The load-bearing capacity is not a problem since the slab was designed with an overload of 500 kg/m² (5 KN/m²). The slab on which the greenhouse is built is made of concrete. More precisely, it's a mixed structure – steel and concrete. This allow great freedom for building the greenhouse. As the building is not very high, the wind load is not too high. Nevertheless, we have to consider the connections with the existing building. The deformations of the part of the greenhouse in contact with the existing building (north facade) have therefore been strictly controlled.

Waterproofing issues are quite tricky because the material has to be resistant to wear and tear and shock, while being stable and easy to maintain. The option of a sealing protected by another material is also considered : waterproofing can then be an unbounded membrane with a protection. The structural connection with the building underneath will also be studied so as not to interfere with the load-bearing structure or the waterproofing of the roof.

For the greenhouse, a light metal structure and walls with a good degree of insulation has been prioritised since the greenhouse will be heated. Steel allows for a slim structure that casts minimal shadow. Glass is resistant, with a good degree of light transmission. Double glazing transmits less light but provides better insulation for the greenhouse (U=1,2 W/m2K). Nevertheless, double glazing achieves a light transmission of +/- 89% with the new available materials.

The greenhouse is built in the city. It will also have to be aesthetically accepted and even add value to the building. The typical profile of greenhouses seen outside cities may therefore not be suitable and require a dedicated coating. The RTG will have to be aesthetically accepted and bring added value.

Construction risks has been mastered by the IFSB's expertise : efficiency, safety measures related to maintenance and accessibility are all elements taken into consideration for this project. All calculations have been performed in accordance with Eurocodes. This means that the experiments will be easily reproducible throughout Europe.



Energy management

Before studying the energy savings of the greenhouse, we need to know exactly what the adjacent building has to offer in terms of energy and CO_2. Thus, air flows from offices and classrooms have been identified and are monitored. We also studied the emissions/flows from the kitchen and the restaurant to re-inject them into the greenhouse. These air emissions could bring thermal energy inside the greenhouse from air that is 3 to 6°C warmer than the outside air (according to the first results of monitoring carried out in autumn). The monitoring of the greenhouse will allow us to quantify the energy gains brought by air from the ventilation of the building. In addition, this air will be more CO_2 loaded since it will be extracted from the interior of the building where many people are trained.

CO_2 emissions will be monitored to know the recovered quantity and the "cleaning" effect of the air (less CO_2, more oxygen). This inter-connection of building structures is also positive for plant growth because CO_2 is the main feedstock of photosynthesis.

On the other hand, it will also be possible to use the greenhouse to heat the building. This will be achieved through less energy loss through the roof of the restaurant and through the south side of the IFSB auditorium. This gain is difficult to monitor but we can study it from a theoretical point of view.

For the greenhouse itself, different elements should be studied.

- The walls of the greenhouse will have a double glass layer (U=1.2 W/m²K) to guarantee better insulation. Calculations made over a period of several years clearly show that, for a heated greenhouse, savings mainly come from wall insulation.
- The building will be designed to be potentially dismantled in the spirit of circular economy. The materials – glass, steel, and concrete (for the foundations) – are easily reusable or recyclable. The quantity of CO_2 used to manufacture the materials used to build the greenhouse will therefore be evaluated.
- The greenhouse itself will be designed to reuse the CO_2 and heat emitted by the IFSB building. As for heating, we will take advantage of the greenhouse construction to replace the current pellet boiler by a more powerful but also more efficient one. Finally, to complete the "green" energy supply of the greenhouse, the largest possible surface area of photovoltaic panels and a few thermal solar panels will be installed.

Production

The production initially planned in the greenhouse was exclusively oriented towards quality tomatoes grown on MG® multi-gutters made of steel coated with polyester. The maximum load on each gutter is 15 kg/m.

The greenhouse will be heated by hot water pipes distributed at the foot of the perimeter walls to enable year-round production.

In a second phase, assimilation lighting is planned for better tomato growth in winter. This will require blackout curtains on the greenhouse periphery and ceiling. These are expensive but mandatory (light pollution is prohibited). In order to ensure a constant climate throughout the greenhouse, we a mechanical air circulation system will also be installed.

Hydroponic cultivation is relatively simple to organise and will allow us to :

- work with a single climate,
- work with a single fertilisation system
- take advantage of the great height of the greenhouse (7.5 m)

It appeared in the business model that it would be difficult to achieve sufficient profitability with a monoculture. We therefore adapted our project by keeping half of the surface in hydroponics for tomatoes, while the other half will consist of "tower gardens" where other vegetables will be grown. Of course, these crops (e.g. cucumber, pepper) will have to adapt to the climate control designed for tomatoes.

The expected climate for vegetables is above 18°C. Production will take place over 11 months from end of January to end of December. This will leave us one month to do the cleaning and maintenance necessary for the proper functioning of the greenhouse and will avoid heating during the coldest month.

PILOT PROJECTS

Feedbacks from Pilots developed within the framework of the GROOF project

GALLY, OPERATED BY LES FERMES DE GALLY (SAINT-DENIS, FRANCE)

By Caroline Robin (Fermes de Gally, Fr) and Amandine Galli (Fermes de Gally, Fr)

Pilot Id

One of the four GROOF pilot RTGs is located on the site of the "Ferme Ouverte de Saint-Denis", near Paris (FRANCE). The farm is dedicated to production and education; it covers 2.5 hectares. It currently produces vegetables on 1.7 ha area and in a 250-m² greenhouse. It also receives citizens, families, and companies eager to discover the basics of farming, healthy food, and nature, and how the farm works.

The farm is managed by Les Fermes de Gally, a French group of family companies specialised in landscaping and devoted to bringing nature and farming in and around the cities.

The 360-m² RTG is dedicated to vegetable production to supplement the existing production of the farm. The goal is to promote the ambition of the GROOF project with a greenhouse solely dedicated to production. Visitors will be able to walk on a platform located on the east and south sides of the RTG. Inside the greenhouse, vegetables will be produced on hydroponic systems. This will create a flexible production tool, to change the crop, if necessary, in order to follow the market. The stakeholders also want an easily manageable greenhouse, sustainable over time and in the way of producing vegetables.

Business – value creation

There is a small shop on the farm that sells fresh products to local people, so successfully that it quickly runs out of stock. So, the ambition is to increase production to meet the demand. Unfortunately, the property cannot be expanded because of urban constrains, so an RTG is a logical solution. Producing on roofs is a wonderful opportunity to increase the production area. The RTG has been installed on the only flat roof available for the farmers to work under controlled conditions, allowing to increase yields without having to deal with soil pollution.

In fact, the soils of the farm, just like most urban grounds, are polluted with heavy metals, so that leafy greens cannot be produced. Leafy greens are produced in soilless systems in the greenhouses present on the farm. Due to the success of this production, the farm continues to produce them there, therefore needing more greenhouse surface to grow crops with high climatic requirements, such as tomatoes or peppers, but building a new greenhouse was not possible on the ground : the whole surface is currently used for mechanised production and teaching activities, and local rules forbid an extension of covered surfaces. An RTG would solve both space and urbanism issues.

The main strength of the project is that the greenhouse is not the only economic resource. The RTG belongs to a worldwide project that will soon be economically viable. The future building will support the project development. The philosophy of GROOF is already fully represented on the site of the "Ferme ouverte de Saint-Denis", i.e. farming, awareness, proximity, and sustainability on many aspects. This RTG will be fully appreciated by real customers.

The urban greenhouse on the farm is part of a corporate ecosystem.

The objectives, the organisation of production and the economic model are linked to the fact that the greenhouse is included in the operation of a 2.5-hectare farm, itself included in the operation of all the farming and landscaping businesses of the Fermes de Gally.

Installing an RTG on a building to be refurbished gives great freedom to define a fully functional production by adapting the building to farming constraints. This will have a big impact on yields inside the greenhouse, as everything will have been designed for production.

However, the project also has some weaknesses. As yet it is hard to justify such an investment for tomato production. We chose to design a productive greenhouse with limited public access to lower investments. Combining several activities on the farm and developing both affordable and high-value products is a key project. Once again, we bet on the flexibility of the infrastructure and on our capacity to react to market evolutions.

Construction

The host building (an old steel-structure shed) turned out to be too weak to bear the greenhouse and farming activity. The building will therefore be partially destroyed to be rebuilt with a more resistant structure (a 500-kg resistant hollow-core slab) and suitable for rooftop cultivation or a light greenhouse. The preserved part of the building will be insulated to improve its energy efficiency. Heat storage and exchanges are the core of the project, and the building structure will be made of concrete with large glass facades to collect heat.

Concerning the covering material, we chose an inflatable double layer greenhouse, with a multispan polycarbonate greenhouse. Polycarbonates have the advantage to provide a good balance between cost, energy efficiency and weight.

By choosing a greenhouse dedicated to production and not intended for the public, we will be able to set up a greenhouse close to the greenhouses of peri-urban professional market gardeners. Through this project, we want to demonstrate that we can build efficient and economically viable RTGs. Another important advantage of polycarbonate is its low weight; this facilitates the load management of the greenhouse. Nevertheless, such greenhouses require good anchoring because their low weight does not compensate for the wind forces.

Les Fermes de Gally was willing to work with a lightweight production system. In this context, the raft system was rejected. Hydroponic gutters with a dripping system on cultured breads will be used to grow tomatoes and other fruit-vegetables, as a lightweight and productive technique. We are studying the irrigation system to make closed-loop cultivation possible.

Energy management

The concrete slab has been thickened to increase the inertia of the whole building. When the outside temperature is lower than the temperature in the greenhouse, the slab will start giving back the calories it has stored. Thicker slabs have increased heat storage capacities. Thus, the greenhouse will stay warm overnight.

The polycarbonate of the northern facade will be supplemented by a concrete wall to improve the greenhouse insulation and decrease the loss of calories from the colder side of the building. This wall will save 20% of energy. Moreover, it will store heat by catching the calories from the sun and the greenhouse, and therefore mitigate the temperature drop at night.

One major limitation of the approach was to find a greenhouse builder eager to build the greenhouse we designed. Even if the shape is quite traditional, our first choices of materials and specifications did not match with builders' priorities, and we had to lower our ambitions to get the greenhouse built (for instance, no builder wanted to install ETFE over less than 2 hectares).

Production

The goals of this greenhouse are to increase the production of the whole farm, and to make the farm more self-sufficient by producing all the plants needed to respond to the local demand.

The building is a new one, so the greenhouse was designed as part of the overall project and was made to be a high-performance greenhouse, while staying simple, low tech, and as cheap as possible Therefore, no light will be installed to grow vegetables, and the heating system will only be used in case of emergency at the start of the production, in March. The production will then proceed until the end of October. As a result of the simulation of the energy needs according to the extend of the production cycle, this production window allows for the longer energy-efficient cycle of production.

For the first year of production, the growing system could be split into two categories : 210m² of cultured breads lying on gutters, and roughly 100m² of heightened gardening plots, both being irrigated by a hydroponic dripping system.


EVO SUPPORT

PILOT PROJECTS

Feedbacks from Pilots developed within the framework of the GROOF project

SERR'URE, GEMBLOUX, OPERATED BY ULG (BELGIUM)

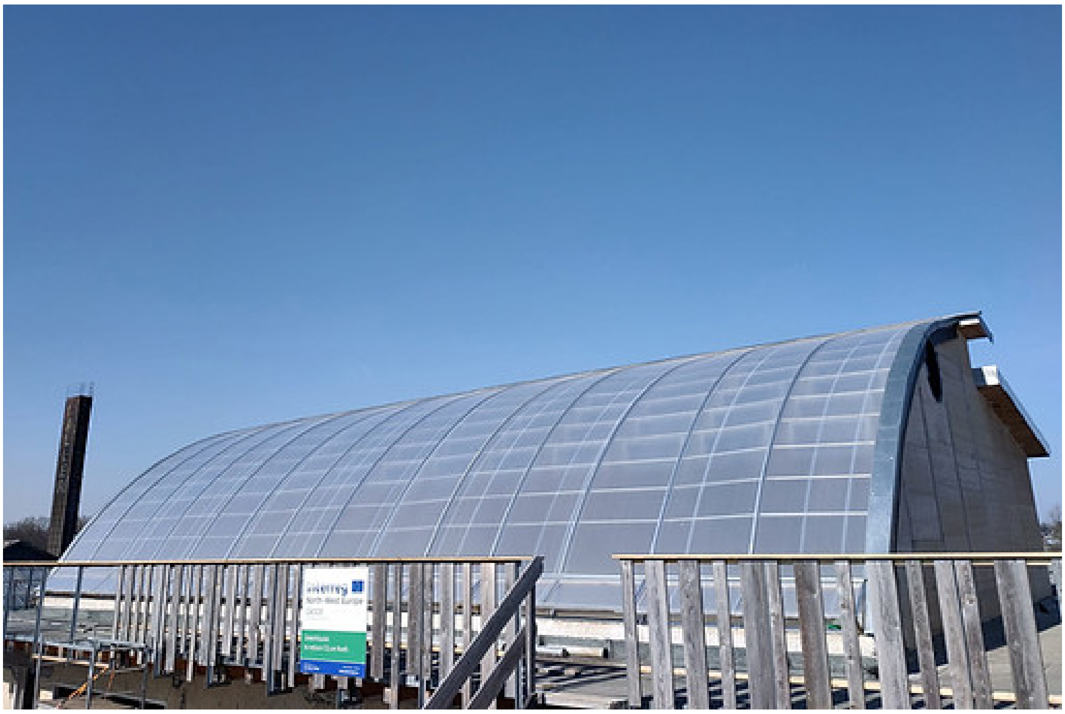
FRESH, BETTEMBURG, OPERATED BY IFSB (LUXEMBURG)

GALLY, SAINT-DENIS, OPERATED BY FERMES DE GALLY (FRANCE)

BÜRSTADT, OPERATED BY EBF (GERMANY)

BÜRSTADT, OPERATED BY EBF (BÜRSTADT, GERMANY)

By David Volk (EBF, DE), Pierre Raulier (ULg, BE)



Pilot Id

The RTG is in Bürstadt, between Frankfurt and Heidelberg (Germany), on the roof of the packaging hall on a farm owned by ebf. The packaging hall is a building from the late 1950's, and right now it is heated by fossil fuels. In several iterations the heat supply on the whole site is going to be replaced by renewable heating in the next years. The solar greenhouse has a 160 m² growing area and is designed to have a low heating demand, produce electrical energy, and serves as a solar collector for the support building. Altogether, it achieves a net positive energy balance over the course of one year of operation.

EBF has been specialised in industrial and horticultural energy management for more than 25 years now and is implementing new technologies and systemic solutions in the horticulture business to help transform the food production sector and make it more sustainable and truly future proof.

The RTG is implemented within the regular operation of the whole site. It serves as a unique selling point for the farm and shows how RTGs can increase the farming capacity without increasing the land use.

Business - value creation

The RTG project and the whole farm serves as a showcase of the EBF approach for an economically competitive horticulture business. Due to the low energy demand of the solar greenhouse and the flexible year-round operation, the farm can supply markets, restaurants, and customers with fresh vegetables directly on the farm all year round.

The greenhouse growing space as well as the rest of the farm are being rented out to a chili pepper specialist who uses the site for organically grown products and ships them directly from there.

This gives ebf the possibility to examine the energy flows and function of a fully operational solar greenhouse responsibly handled by an expert in horticulture.

Construction

The packaging hall is built in a traditional way, with heavy walls and strong foundations. It is structurally stable, even after more than 50 years of existence. The roof itself consisted of wooden beams that were strong enough for the previous roof covering but could not bear more than the corrugated Eternit® roof, which itself was partly damaged and not fully sealed anymore.

The old roof and the whole beam structure were removed to install the new rooftop platform. After the removal of the roof, a concrete ring beam was placed on top the walls. Then, wooden roof beams were added, and the bearing structure was finished with a platform made of OSB boards. Since substantial changes in the roof structure had to be made, it was possible to generate a bearing capacity of the platform of 2.5 kN/m² depending on the location. At the backside of the greenhouse, due to the range of the beams the potential load is substantially higher.

The greenhouse consists of a light-gauge steel frame connected directly to the wooden roof beams. The platform and the connection to the steel frame are coated with a special waterproofing material that will prevent water damage to the bearing structure.

The outer shell of the greenhouse is a heavily insulated hempcrete wall on both sides and the back. Parts of its roof are insulated as well, with light weight hemp straw. The arched south side is covered with a highly transparent double layered ETFE coating. For cold nights, a thermal blanket will be rolled down from the greenhouse top to reduce thermal radiation losses.

A walkway around the greenhouse was established to be able to get access to the greenhouse from all sides and to collect rainwater.

Energy management

The main goal of the solar greenhouse is to reduce the energy demand of food production while being operated all year-round. This is done by creating a heavily insulated outer shell that will reduce heat losses.

An important problem for greenhouses in summer is overheating. The solar greenhouse will use PV systems installed inside directly under the film to generate shadowing while generating electricity. If there is no need for shadowing, the PV system will get rotated out. Additionally, ventilation flaps are installed on the bottom south side and at the highest point in the greenhouse. These strategically installed openings generate a natural flow through the greenhouse that cool it down with fresh air without requiring forced ventilation and thus no energy demand. This is possible due to the high transparency of the ETFE film. Since the PV panels are not exposed to atmospheric influences they can be light weight and thin.

Due to the insulated and opaque side walls, the total incoming sunlight is reduced in comparison to other greenhouse types. Therefore, internal heat management becomes more important. This is mainly managed by insulation that will reduce radiative heat losses, and a thermal blanket which will be used to save energy and prevent direct sunlight in the intense summer heat.

Production

As all the housing services and other devices for the greenhouse will be installed in the support building, they don't take up any space inside the greenhouse, increasing the available growing space.

Production is realized with substrate-based hydroponics. Therefore, Dutch buckets with a comparatively large volume are used. The growing media will be composed of a classical planting soil enriched with Tera Preta. It will be reused several times over a few growing periods with additional enrichment in the greenhouse, and then as replacement soil for outdoor growing to reduce the maintenance workload.

First, a selected variety of chilies are grown. Since the RTG is part of a larger operation, it will be used in a flexible way, within the boundaries of normal operation. Harvesting and packaging will therefore be directly done by the farm workers without any restriction.

One of the most important fields of application is the utilization of this rooftop greenhouse for seedling cultivation. The low energy demand helps with starting earlier in the year and therefore having the possibility to enter the market with fresh products early. Since seedling cultivation does not need much space, the seedlings of the whole site can be produced in the rooftop greenhouse.

FAQ

By Nicolas Ancion (ULg, BE), David Volk (EBF, DE), Ismaël Baraud (CSTB, Fr), Laurent Reynier (CSTB, Fr), Bernard de Gouvello (CSTB, Fr), Marcel Deravet (IFSB, LU), Nicolas Brulard (Fermes de Gally, Fr)

ABOUT ENERGY

Finding a good system to heat the greenhouse in winter (to avoid winter frost)

A good system to heat the greenhouse in winter is based on two important aspects :

- Getting sufficient energy into the greenhouse
- Avoiding energy losses.

The first aspect is in line with the main goal of the greenhouse – plant production. The primary energy source is sunlight, which is mainly influenced by :

- The greenhouse design and orientation
- The covering material
- Obstacles in the surrounding area

Since solar intensity is low in winter, further energy sources from commodities should be included :

- Waste heat capture from residential and office heating
- Industrial waste heat sources
- Additional thermal solar energy with hot water storage
- Waste heat from the household equipment like air conditioners and ventilation.

All the above-mentioned aspects might be enough to keep out the winter frost but are often accompanied by a high installation cost and/or operation cost. Therefore, avoiding energy losses might be an opportunity to investigate :

- Sidewall perimeter insulation, especially important for walls facing north, where no sunlight can be captured
- Removable transparent insulation : while having decreased transmissive properties, they can be used to keep the heat inside, especially if there is no winter production and not all light is needed
- Heat-saving devices (heat shields) in the greenhouse, which are standard techniques but might turn out to be costly too.

An additional measure, one can also reduce the heated space in the greenhouse and adapt it to production; two significant possibilities can be investigated :

- Only heat the water used for hydroponics to keep the plants warm while not heating the greenhouse (crop-dependent)
- Used fleeces or plastic tunnels over the crops to further reduce the heated space

All above-mentioned techniques can be combined in an optimal way to increase efficiency while keeping costs low.

How to enrich the atmosphere of greenhouses with CO_2 and how to succeed in doing so

Enriching the greenhouse atmosphere in CO_2 can be a good opportunity to increase efficiency in a greenhouse environment. Plants use CO_2 in combination with sunlight to grow, while emitting oxygen. With more CO2 in the air, crops can improve their growth. But they also need more sunlight to use the additional CO_2.

Here are possible enrichment techniques :

- Using passive CO_2 enrichment techniques, such as ventilation of exhaust gas from an office building or other sources
- Using the chimneys of the heat-generating facilities already installed in the building or needed for the greenhouse, as well as possible other sources surrounding the greenhouse
- Using active systems that primarily rely on the combustion of fossil fuels

In most cases, exhaust gases can be directly used in a greenhouse without further treatment. Passive systems are generally preferred because they do not use valuable resources and do not generate further emissions.

CO_2 can be generated by heating the greenhouse. This key aspect creates a synergy between heating the greenhouse and enriching its air in CO_2. One final remark is that CO_2 enrichment is often at odds with ventilation needs. In summer, when the benefit of high sun intensity and CO_2 enrichment can have the highest synergies, the greenhouse is also likely to overheat, which may in turn damage the crops. If no active cooling system is used, ventilation is key, but also reduces enrichment. Therefore, there has to be a trade-off in a greenhouse between these two aspects, especially if enrichment is active and resources are used.

How to combine PV panels or solar panels with an RTG

Finding a way to implement PV systems along with an RTG can be helpful to maximise the use of energy from incoming sunlight. Several techniques are possible, but it is important to make sure that the plants in the greenhouse are prioritised for sunlight exposure, otherwise plant growth is sacrificed for energy production. On the other hand, during most of the summer days the maximum amount of sunlight exceeds plants requirements by far and creates a hot climate in the greenhouse that requires shadowing. Using the PV system for shadowing helps to cool the greenhouse and also usually generates enough electricity to maintain a self-sufficient operation of the greenhouse systems. Therefore, an adaptable system is necessary which does not impede plant growth.

New photovoltaic panels are being developed, that would allow the light waves necessary for plant growth to pass through while producing electricity.

How to manage condensate water in the greenhouse

Plant growth and high solar intensity cause the greenhouse air to accumulate humidity that condensates overnight when the air cools down. This leads to cold water dripping on the plants, making them vulnerable to pests and fungal infections. Additionally, this can lead to further contamination when outside air mixes with inside air and pollutants are transferred to humid air.

Measures can be taken to prevent condensation :

- Ventilation reduces the amount of humid air and adds fresh and drier outside air. The disadvantage is that a lot of the water in the air comes from plant watering; this water is lost, and this increases the resource demand of the greenhouse
- Cooling devices in which the water condensates and can be reused directly can be used. This implies a high energy demand
- It might also be feasible to circulate the air through several colder areas in the bearing building, with designated condensate reservoirs (see part MANAGEMENT OF RAINWATER FOR THE SUPPLY OF ROOFTOP GREENHOUSES of the Chapter EXPLOITATION).

Since condensation cannot be prevented, some greenhouse builders use specifically designed heat bridges to generate condensate at certain spots where it can be managed more easily and reused.

Condensation is especially problematic early in the morning, and strong ventilation currently usually solves the problem. It can be useful, but it also implies a great energy loss.

How to optimise the greenhouse cover for optimal production in summer

A heat shield can be installed in addition to the already mentioned PV system to operate a greenhouse in summer. A heat shield is a moveable screen consisting of a material that blocks the sunlight partially or totally, leading to a reduced cooling demand. This also leads to reduced available light for the plants, which might result in reduced plant growth. It should be noted that plants get more than enough sunlight to grow in most cases and places in summer. Excessive light stresses the plants and reduces their ability to grow.

Potential benefit from installing an RTG on a car park

Using a car park that is not in operation anymore can have some benefits. First and foremost, finding a new way of operating a disused sealed land has a lot of benefits for the town itself. Additionally, car parks are designed to bear high loads, they can usually bear a greenhouse without any necessary reinforcement of their rooftop. Moreover, roof accessibility is generally a lot better than it is for comparable projects (the usual logistics problems of RTGs are mitigated). On the other hand, some of the usual benefits of a rooftop are missing :

- A carpark is usually not heated, therefore the waste heat potential is absent
- Quite often the different levels are not closed so that the greenhouse will be ventilated from underneath, increasing transmission losses

Furthermore, the former carpark might bring uncontrollable contamination into the greenhouse.

Use of a water tank in the greenhouse to promote thermal inertia; how to do so

In principle, this is possible, but implies restrictions mainly regarding the weight and size of the tank. It is important to check the bearing capacities of the building. Additionally, RTGs can be limited in size, so a larger water tank can take up important growing space.

More generally, it is more appropriate to place the tank on the ground or underground when harvesting rainwater, even if this leads to an energy demand for the pumps.

How to improve the energy efficiency of the host building or RTG through the RTG design

This question is heavily influenced by the project and needs thorough examination in each case. However, basic possibilities can be checked if possible. Here are a few outlines that add to the previously mentioned answers :

1. If some of the greenhouse surfaces face a direction in which there is no sunlight coming in (north), these surfaces can be strongly insulated. The heat from the building, even insulated, will limit losses

2. If walls of the existing building are available, using them will decrease the surface of the greenhouse and reduce transmission heat losses

3. If there is any kind of energy waste on site, using it can be helpful to increase energy efficiency

4. Trying to cover the greatest possible roof area with the RTG will also reduce transmission heat losses from the building

For example, energy efficiency was improved by 13% in Gembloux by adopting a lean-to design. Nevertheless, each project is different and needs to be assessed.

FAQ

By Nicolas Ancion (ULg, BE), David Volk (EBF, DE), Ismaël Baraud (CSTB, Fr), Laurent Reynier (CSTB, Fr), Bernard de Gouvello (CSTB, Fr), Marcel Deravet (IFSB, LU), Nicolas Brulard (Fermes de Gally, Fr)

ABOUT CONSTRUCTION

Is building an RTG allowed ?

Any such construction requires a building permit issued by the municipal administration. Each municipality has its own regulations, and this is therefore the first step to be taken : make an appointment with the technical service of the municipality in which you want to build the RTG.

Building a greenhouse on a roof is something new, and it is an innovative solution. It is like adding a new level on the top of a building. As far as the different kinds of works on a roof are concerned, modifying a building or adding a new level is allowed, especially on a flat roof, if the structure can bear the load of the greenhouse and related activities.

A building permit is indispensable!

Could the greenhouse be used as a public space ?

It depends on the classification of the flat roof and on the greenhouse target (production, social role, educational role, etc). If the flat roof is classified as “accessible”, people can have access to it. The sub-classification is private or public. Depending on it, several criteria must be complied with concerning public access (fire safety, security access, capacity, etc.). The RTG will be built according to this choice. Furthermore, calculations and safety standards are different for an RTG open to the public.

The sanitary aspect of production must also be considered. In a production greenhouse, the public is generally not welcome inside the greenhouse.

How does one determine the load-bearing capacity of the roof ?

The load-bearing capacity is calculated by a structural engineer and the design office according to a European standard method (Eurocodes). The calculation hypothesis must take safety, the exploitation load, and the accidental load into account.

NB : for fish tanks or for specific heavy loads, a specific calculation must be done for the roof area concerned by this overload. It might be more interesting to install them on the ground below, which also needs to be validated for these loads.

What should the minimum load capacity be ?

The minimum load capacity is 400 kg/m² or 500 kg/m² for all kinds of accessible roofs. If the roof was designed for garden use, a greater load has to be considered for the calculation. If the roof is also used for vehicles or parking, the minimum load capacity is calculated based on the type of vehicles to be parked. In the case of public reception, a load capacity in the order of 400 to 500 kg / m² is used.

For greenhouses that are not open to the public, a load of 150 kg/m² is required, to which the weight of the growing elements and the weight of the greenhouse itself must be added.

If the load-bearing capacity is OK, how much does it cost to install a "techno-structure"? And how does it work?

A new techno-structure intended for building a greenhouse on a flat roof is generally made of a steel frame anchored in the concrete sub-structure and superimposed, with or without a new floor. These kinds of techno-structures are nearly the same as for every kind of technical equipment or super-imposition on a flat roof. The cost depends on the configuration of the roof, the size of the greenhouse and local constraints to build it.

Which type of access needs to be planned?

Production in the greenhouse requires human presence daily, and a daily flow of material, delivery, and storage. Access must be comfortable, safe, and sustainable. Several kinds of access can be planned, i.e. a lift for people and materials, combined with stairs for people visiting the site, a footpath around the greenhouse for circulation. Access is the same as it is for all kinds of accessible flat roofs.

How to waterproof a roof after building an RTG?

The waterproofing of the flat roof is important to protect the structure and the building below because the greenhouse is not considered as the roof of the building. The greenhouse is not waterproof, and the production activity uses water. Special attention is required to avoid disputes or trouble in the building below. Like any kind of flat roof, waterproofing must be properly designed and installed, using high-performance products. In case of a dispute, investigating the causes of a leak or an infiltration can be quite expensive.

What features should the building structure present to have a greenhouse rehabilitated or integrated on its roof?

The building structure should be resistant at all levels because the overload from the greenhouse will be borne by the whole structure, not just the roof. The structure will have the right bearing capacity at the level of its foundations and at all other levels.

Advantages & disadvantages of a metal structure on the roof; how much could it cost ?

A metal structure is the first technical solution identified for building a greenhouse because conventional greenhouses are made with it. The design is well known, calculation methods are well known, installation of the steel frame is well known.

The average cost is 175 €/m². Nevertheless, an average cost is difficult to claim, because it is linked to other parameters such as the existing structure.

Advantages : the new structure does not need to cover the whole roof, and the structure can be built in several phases (to limit investment)

If the building is not too high, the new access should not be costly.

Disadvantages : still costly. A new access needs to be built; waterproofing and insulation still need to be re-examined.

How should I install and manage water storage ?

Each water storage equipment requires an analysis of the local volume of rainwater per year and per month to determine the ratio of its use for the greenhouse. Water tanks are considered as a heavy overload, and their layout depends on calculations linked to the structure. If possible, the water tank will be located on the ground or belowground, and the harvested water will be pumped back to the rooftop to be used. If the storage tank is in the greenhouse itself, specific precautions have to be taken (see part MANAGEMENT OF RAINWATER FOR THE SUPPLY OF ROOFTOP GREENHOUSES of the Chapter EXPLOITATION).

The European standard EN 16941-1 details all the requirements for a rainwater harvesting system.

What are the different possibilities for the greenhouse envelope ? Lifetime (easy to change ?) + price

Possibilities for RTG envelopes are the same as for all conventional greenhouses. Considering the localisation on a roof, safety glass or polycarbonate might be more adapted for RTGs.

The lifetime and the durability/resistance of the material is a very important criterion because each replacement of the envelope is expensive due to the stoppage of the production activity.

Replacements are also costly because the work must be done at +/- great height. Lifting devices are therefore necessary.

FAQ

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ABOUT PLANT PRODUCTION

What can be produced in an RTG ?

All kinds of plants can be produced in an RTG according to your project : vegetables, herbs, as well as ornamental plants can be cultivated.

The choice of plants is first determined by the market, through a market study. What do you want to sell, and to whom ? What kind of product ? Which price are the customers ready to pay ? Is there any competition ?

Then the building characteristics and the RTG will help to define technically the possible and relevant economic modes of production.

Several kinds of plants with the same climatic needs or one specific crop can be cultivated.

As the urban context is unique, we recommend focussing on the specific need of the market, using freshness and proximity of production as an asset.

The intensive production of root vegetables is not really of interest in RTGs as compared to field production.

What plant production techniques do you recommend ?

It is not possible to recommend a single production technique. It must be adapted to the chosen species, environmental constraints, and is very dependent on productivity expectations. For example, a mono-specific tomato production can be carried out in a vegetable garden, in pots or in a soil-less culture substrate, but the surface area, the equipment and the cultivation technique (watering, fertilisation, ...) will have to be adapted.

How to plan production ?

Once again, this question needs to be considered according to the yields and expectations inherent to the crop and the selected varieties. Planning should first be consistent with market expectations and workforce availability. It is obvious that some crops have a seasonality of consumption, so it is easy to plan production from seedlings or young plants. For example, basil is mainly consumed in summer, and its cultivation is known to require 6-8 weeks on average to reach a marketable stage from seedlings. Staggered harvests are also possible to produce in the long term, but the principle remains the same : it is necessary to know how to grow the plant and to adapt the conditions (light, temperature, fertilisation, etc.) if necessary in order to have an early or late production compared to the normal period.

Is lighting indispensable ?

The addition of artificial light is neither mandatory nor necessary. It can be beneficial to certain crops or for forcing others, but it represents costs and substantial electricity consumption. Urban integration also has to be considered. Does artificial light match with municipality rules, neighbour expectations or the global image of the project ? Many horticulturists whose production comes from classical greenhouses do not use any lighting.

Is heating indispensable ?

It is not necessary to have a heating system, but it substantially widens the scope of possibilities in terms of crops and also makes it possible to grow plants all year round. Depending on the regions and the winter temperatures and in spite of a good mulching, heating can mitigate cold-induced damage. A lot of traditional field greenhouses are not heated.

Anyway, bioclimatic design dramatically reduces the heat needs and maintains a minimum temperature in winter.

Finally, it is recommended to couple the heating of the greenhouse to that of the building when possible to optimise energy flows.

What crops can we grow in a cold greenhouse in the wintertime ?

In an unheated cold greenhouse, it is possible to produce mainly winter-flowering horticultural species such as pansies or primroses, winter vegetables such as cabbages, beets, turnips and chard for example, but it is also possible to consider the multiplication of nursery plants, which could be very interesting for municipalities for example.

In urban areas, the heat island effect and local microclimates can create specific roof conditions favourable to crops (for example, ~30% of the building's energy lost through the roof can maintain good temperatures in the greenhouse).

Is a ventilation system indispensable ?

It is indispensable and essential! It allows the temperature in the greenhouse to be regulated by lowering it when it exceeds the set or desired temperature. It is also necessary for the good health of the greenhouse and of the plants to remove excess moisture and renew ambient air.

What types of substrates can be used ?

There exist many horticultural substrates adapted to different types of crops (herbs, seedlings, vegetables, horticultural plants, etc.). They differ from one another in their composition, structure, lightness, fertilisation, etc.

They greatly facilitate the success of crops. In the case of soil-less culture, several possibilities are also available, including straw, sphagnum, peat, sand, etc. The choice will be made according to the crop type, the species, and care must be taken to adapt fertilisation.

Growing media formulation requires great expertise for a perennial substrate adapted to the context (substrate weight, CEC, water retention and drainage, acidity). Contact growing media suppliers.

How should I feed my plants ?

Most commercial potting soils are enriched with fertiliser, but the amount is often insufficient for the entire crop. It is therefore necessary to add mineral or organic fertilisers in a solid form at the base of the plants or in a liquid form in the irrigation water, known as ferti-irrigation. The latter is essential in the case of soil-less culture and must be managed according to the developmental stage of the crop, its nature and what is expected from it.

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ABOUT BUSINESS

How can I find a producer ?

Start by meeting farmers before building the greenhouse to make sure that the kind of greenhouse is interesting for them! Then make them participate to certain steps of the RTG design.

How can I involve a farmer in the project ?

Considering all points of view is a complex and very important task. Involving the future RTG users is a key success factor for your project. The sooner they are in the loop, the better.

The use of this rooftop should be considered to save time and money in the design and construction of the work. Management and maintenance costs should be considered, as well as operating constraints.

Will the greenhouse be accepted by the inhabitants / residents / co-owners ? How can I get them involved ?

The project might not just need to be accepted, but welcome and expected. Several techniques can be used. You could organise personal meetings and then group meetings.

But for that, you need to clarify the expectations and fears of the different users and people impacted by the project. Urban greenhouse projects have been blocked and cancelled following complaints from residents.

Online tools can be used at each step if face-to-face is not possible. The first steps should be done before or at the beginning of the design of the greenhouse.

NB : Once the usage has been chosen collectively, greenhouse management and internal regulations might be needed (and co-created before).

This point is often forgotten but it is also crucial in such a project. These people can be reluctant at first and become real ambassadors of your project if you devote some of your time to them.

How much does it cost to build a greenhouse ?

As said in the construction questions, a steel-framed greenhouse costs around 175 to 220 €/m². This cost can be multiplied by 3 to 15 depending on the modifications to be made to the building or the required production devices.

How can I build my business model around my project ?

See part PROJECT OUTLINES AND STRATEGY of the Chapter PREPARATION.

How can I find a roof ?

Tips : your network, the municipality, the GROOF network, Google earth, etc.

Are you sure you want a roof ? Do you need an urban farm ? An urban greenhouse or an RTG ? Greenhouse-friendly rooftops are rare, so find them but also prepare a plan B! And walk around the city.

How can I convince investors and public authorities to fund the project and be part of it ?

Your arguments need to be adapted to each prospect : know their needs and fears to reassure and convince them. Show them what your project can offer them (e.g. a green and innovative image for public authorities) Show how your project is different from the others.

Remember : you are not alone. The GROOF European project has already developed strong knowledge on this subject!

How can I find a partner ?

Before finding a partner, it is very important to be very clear about why you are setting up this project.

So be clear about your skills and which tasks you wish to accomplish in this project.

Then ask yourself what complementary skills are needed for your project.

If you are very clear with these elements, then take time to talk about your project on every occasion. Professional events (conferences, masterclasses, etc.) as well as private events are opportunities to share about your project and hear about someone who could be the ideal partner. You can also create these situations by meeting the local public authorities, business owners or managers, stakeholders of urban farming, and so on.

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