Quantifying carbon and water exchanges of building green envelopes via modelling informed by observations

Host laboratory: DESR/CNRM, Météo France-CNRS, UMR3589, Toulouse, France
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Context

Many cities in France and around the world are seeking to develop and balance their vegetation cover, including in the most urbanized areas, in order to fight climate change. For urban areas, which have a strong thermal regulation issue, the available ground space is generally very limited to implement a network of green spaces (green grids). Greening the building envelopes by implementing green roofs and facades would therefore constitute an alternative or complementary solution. On their own scale and integrated into the green and blue grids, these vegetated systems are likely to contribute to the services provided by vegetation to the urban ecosystem, including the regulation of the microclimate and rainwater, but also the sequestration of carbon from the atmosphere.

In some European countries, the greening of buildings is constantly increasing, as in Germany with 800 ha/year of new green roofs. In France, the deployment of green roofs and facades is not yet widespread, probably because the complexity of their implementation and their supposedly high water requirements remain obstacles in the face of relatively unknown regulation services. Measurements and models to describe all the exchanges that take place within and on the surface of these vegetated envelopes are, in fact, either rare or incomplete. This research project aims to overcome these barriers.

Scientific objectives

The urban climate team of the DESR/CNRM Medium Scale Meteorology Group has an urban microclimate model TEB (Masson 2000, *BLM*) that already allows a realistic representation of the energetic and hydrological interactions between vegetation and buildings for low vegetation (TEB-Veg module; Lemonsu et al 2012, *GMD*), street trees (TEB-Tree module; Redon, Lemonsu et al 2017, 2020, *GMD*) and green roofs (TEB-GREENROOF module; de Munck , Lemonsu et al 2013, *GMD*).

Based on existing tools, this thesis pursues three major objectives:

1) to better understand the radiative, thermal, hydrological, and carbon exchanges that occur specifically within and at the interfaces of two types of building vegetated envelopes (green roofs and facades) ;

2) to improve or describe these exchanges in the model in order to achieve an advanced physical modeling of the interactions between the vegetated envelopes and the atmosphere at the scale of buildings ;

3) to evaluate these systems in different areas of the world, by comparing their micro-climatic and hydrological regulation and carbon sequestration performances with respect to their water needs and local climatic constraints.

Methodology

To reach these objectives, the thesis will be carried out in three successive phases:

1) a literature review of available observations & a state of the art of models :

The review of experimental studies under different climatic regions of the globe will allow the student to understand the physical processes and the challenges and needs of green roofs and facades. A specific focus will be on two super-sites in Berlin, which document exceptionally well radiative, thermal, hydrological processes and states and carbon fluxes: a very large green roof (Heusinger & Weber 2017, *Scie Tot Env* ; Konopka et al 2021, *JGR : Biogeosciences*) and several green facades (Hölscher et al 2016, *Energy and Buildings*, 2018, *Agri Forest Met*).

The review on numerical models will aim to identify the dominant physical processes and the different approaches implemented according to the spatial scales of application.

2) Modelling of green building envelopes informed by observations at Berlin super-sites:

For green roofs, this will involve refining the existing TEB-GREENROOF parameterisation (de Munck et al 2013, *GMD*) with respect to hydrological transfers in the roof substrate and the vegetation characteristics that control CO_2 exchange. Wet periods will support the understanding and the modelling of water flows while drier periods will allow the coupling of processes (water flows + evapotranspiration & CO2 fluxes) to be studied.

For green facades, the aim will be to develop a physically-based parameterisation based on the understanding of the physical processes involved acquired at the beginning of the thesis. One possible approach would be to adapt the existing TEB-Tree parameterisation (Redon, Lemonsu et al 2017, 2020, *GMD*) in the form of a greenery curtain interacting with the wall.

For both types of vegetated envelopes, an important issue will be to evaluate the capacity of the models developed to reproduce the variability of the cooling and carbon sequestration performances according to the local microclimatic conditions (wet, dry, hot periods) and the contribution of irrigation for an optimal functioning of plants.

3) climate simulations involving vegetated envelopes in different regions of the world:

Buildings equipped with green roofs or facades will be simulated under contrasting climatic conditions to compare their performance in terms of microclimatic and hydrological regulation and CO2 sequestration in different parts of the world.

This will involve i) selecting the regions of interest and building long series of atmospheric forcings to feed the model, and ii) establishing a performance evaluation protocol for each system (building orientation, type of vegetation, nature of the substrate, irrigation scenario, performance indicators).

Links with the team research activities

The urban team at CNRM has been dedicated to urban climate research for 20 years. The laboratory's work is internationally recognized and in 2015 the CNRM organized the 9^{th} international conference on urban climate, bringing together 550 researchers from over 60 countries. This research follows three main lines: (1) the improvement of numerical weather and climate prediction models in cities, via the development of the urban canopy model TEB, (2) the continuous improvement of knowledge on urban climate through observation and process studies, and (3) the adaptation of cities to climate change. The thesis therefore proposes to contribute to the first and third research axes, the latter of which has been growing rapidly over the last ten years. It will be based on the ongoing collaboration with the University of Technology of Braunschweig, Germany, which has unparalleled experimental sites for the monitoring and study of green roofs. This collaboration will be extended with the Technical University of Berlin (Germany), which is leading the super site of instrumented green facades in Berlin.

References

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Profile and skills required

The student should have a solid background in atmospheric physics and/or surface processes and surface/atmosphere interactions. He/she should be familiar with urban issues and will be required to cover several closely related topics during the course of his/her thesis: climatology, hydrology and vegetation functioning. This subject therefore requires a taste for multi-disciplinary research, with a vision that is both detailed and synthetic of the themes addressed.

Various scientific and technical skills will be required to deal with the subject:

- bibliographical studies and syntheses, requiring curiosity and a capacity to synthesise,
- data processing and analysis, requiring expert use of tools such as R or Python,
- programming in the urban model TEB, in Fortran90 language, of the equations governing the physical behaviour of the vegetal envelopes of buildings,
- numerical simulations to evaluate the performances of vegetated systems in different parts of the world.

A good initial level and a taste for programming is desired (Fortran90, shell, R, Python) and can be perfected during the thesis by training in the host laboratory.

A good practice of English is necessary in view of the work and collaborations envisaged.