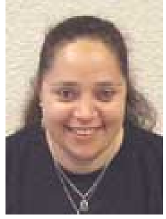

Paper n° 541: The TERRACES project – Qualifying and quantifying the changes in the urban energy balance using vegetative green roofs (VGR)

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1. Introduction

In order to improve the sustainable urban design according to health, environment, energy and climate issues, the integration of vegetation in the cities is promoted. Urban greening is not only a fashion and its success is based on various at the same time social arguments [*Emelianoff, 2007; Cunha, 2009*], economic, sanitary and environmental: extension of the life cycle of the roof [Wong et al., 2003; Teemusk and Summon, 2009], decrease of the rate of CO2 in the atmosphere [*Emilsson et al., 2007*], esthetic attraction of the building and the increase of the urban biodiversity [*MacIvor and Lundholm, 2011*] and the mitigation of the urban heat island [*Takebayashi and Moriyama 2007; Alexandri and Jones, 2008*].

The vegetative green roofs (VGR) could represent a serious opportunity to reach the green and dense compromise, both for the buildings construction and rehabilitation process in the existing dense city centers.

However, urban experts require evaluation and design technical means to promote VGR in their projects, consistent with the existing urban layouts.

Furthermore, the knowledge about green roofing technique is not yet well accomplished because of the multiplicity of VGR typologies and layer intrinsic properties, the complexity of the multi physics transfer phenomena and the interactions between green roofs and their surroundings [*de Munck et al. 2013*]. The evapotranspiration process is the main heat sink of the energy budget for green canopy but is not easy to assess.

2. The abstract

Currently, different urban planning strategies are proposed to cool or refresh micro-climate (especially in summer) acting on the temperature, wind and humidity. The frequently cited cooling devices are physical proceedings such as the vegetation cover expansion. The most prominent examples are the living walls and roofs. The proposed project intends to deeply develop the scientific analysis of the performance and impacts of vegetative green roofs (VGR) on urban climate, environment and health. The scientific approach is conducted with three tasks: 1 - to assess the refreshing potential of a VGR; 2 - to develop relevant indicators dedicated to VGR environmental impacts; 3 - to establish a link between VGR performance and spreading potential in urban zones.

This communication addresses methodology selected, the experimental protocols developed and the first results of the task 1. The aim is to establish a comprehensive coupled hydrological and energy balance of a VGR at the building scale, able to compute microclimate impacts under experimental measurements conditions and climate change scenarios.

Estimation of evapotranspiration by VGR is important to assess the cooling potential of this system, and the purpose is to combine experimental and modeling approaches. In this project, long-term micro-meteorological, thermal, hydrological measurements are achieved on three fully instrumented roof platforms, in the three different partner's locations: Nancy, Nantes and Trappes. Moreover, during one year, monthly measurements of evapotranspiration fluxes have been performed with a specific experimental device. We present a comparison of these detailed measurements in each experimental site to show the influence of the geographic context and of the roofing intrinsic composition. We also introduce a first comparison of the effective evapotranspiration measurements to the potential evapotranspiration theoretical computation. Albedo and Leaf Area Index

experimental evaluation are also ongoing and will be discussed. They directly impact the surface energy balance and are difficult to assess with classical methods derived from agronomy.

3. The methodology

One of the reasons of the temperature increasing in cities is the reduced evaporation from the urban surfaces. Most of the studies on the role of vegetation in town are based on simulations at mesoscale and the result often depends on numerous local parameters as the regional climatic characteristics, the type of building or the composed hypotheses [*Santamouris, 2012*]. This makes very difficult the comparison or the generalization of the conclusions. But all the published works is unanimous on the positive contribution of the vegetated roofs on the thermal of buildings and to a lesser extent the reduction of the temperatures. Estimation of evapotranspiration by VGR is important to assess the cooling potential of this system, in nowadays climate conditions but also under climate change GIEC projections. The magnitude of changes will also depend on the characteristics of the device (vegetation type, substrate thickness, etc.) but also their geographic context.

The task aims to qualify and quantify the changes in the urban energy balance induced by the introduction of VGR. These modifications are associated with the physical properties of surfaces and increased evapotranspiration. This task is organized in 3 sub-tasks (Figure 1).

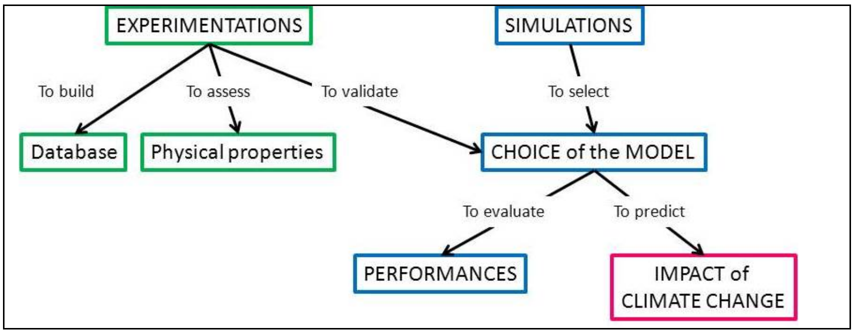

Fig. 1 Organization of task 1.

It is then essential to measure, on various experimental sites the parameters necessary for the validation of the model (sub-task 1.1). Besides the need for data for modeling (sub-task 1.2), these observations will also allow to constitute a database on the physical properties of the VGR, still little known and which can be useful for the whole scientific community. A study of the evolution of the precipitation and the temperatures on 3 target cities within the framework of a climate change (sub-task 1.3) will allow a better adequacy between the choice of the nature of devices, their number and their location. In this frame, the use of the scenarios of the project GICC DRIAS will be relevant [*Lémond et al, 2011*].

3.1 Experimentations

The first step of the project involves three French teams in three different cities which get their own green roof experimental platforms (Figure 2), full-scale for Nancy (~600m²) and Trappes (~300m²) and pilot-scale for Nantes (6 x 2m²). The objective is to compare the different in-situ observations to generalize hydrothermal phenomena description. The thickness and the nature of the growing media are different as the technical and plants technical characteristics and also the non vegetated part (drainage layer, filter, waterproofing, vapor barrier, isolation layer).

Trappes

Nancy Nantes

Fig. 2 The 3 experimental platforms of Nancy, Nantes, Trappes sites.

The measurements conducted on the three experimental platforms are made continuously and point-in-time. A field campaign has been conducted during one year in order to measure the evapotranspiration flux with a specific protocol using a closed evapotranspiration chamber [*Reicosky and Peters 1977*; *Steduto et al. 2002*; *Stannard and Weltz 2006*]. Continuous measurements (rainfall, runoff, growing media water content and temperature, air humidity, air temperature…) have allowed the calculation of the water balance and energy balance of each experimental platform to assess the evapotranspiration fluxes. Results show differences between the three sites but also for each site between the configurations.

3.2 Simulation

The modelization of physical phenomena involved during mass and heat transfer required a good understanding of VGR behavior whose was different from that encountered in the case of a conventional roof. The meteorological conditions changed in a different way because of the presence of vegetation on the roof. To make this effect clearer, we were conducted to study in the first instance the hydrological and thermal phenomena across the VGR components which consisted of vegetation, growing media and drainage layer (porous media). First, the models were detailed for each physical phenomenon in order to propose a model that would appear both accurate and feasible at the same time. Several green roof models have been proposed in the context of this topic. These vary according to the criteria of accuracy, performance and feasibility.

Development of a physical model that describes the thermal and water balance across the VGR is based on urban canopy model Town Energy Balance (TEB) [*Masson, 2000; Hamdi and Masson, 2008*]. The TEB model consists in a parameterization adapted to the specific physical processes established in the urban atmospheric layer. It was developed by Masson (2000) and Masson *et al.* (2013), in order to simulate the turbulent fluxes for urban areas. TEB model was originally developed for applications in meteorology and weather prediction at kilometer spatial scales, or at higher resolution. A previous work was performed to use TEB with VGR [*de Munck et al. 2013*] but only for one study case. In the study presented here, an analysis is conducted on the various climates (degraded oceanic climate with continental influences in Nancy, degraded oceanic climate in Trappes and oceanic climate in Nantes). The physical processes involved to modeling the road surface energy balance by the TEB model are summarized in Figure 3.

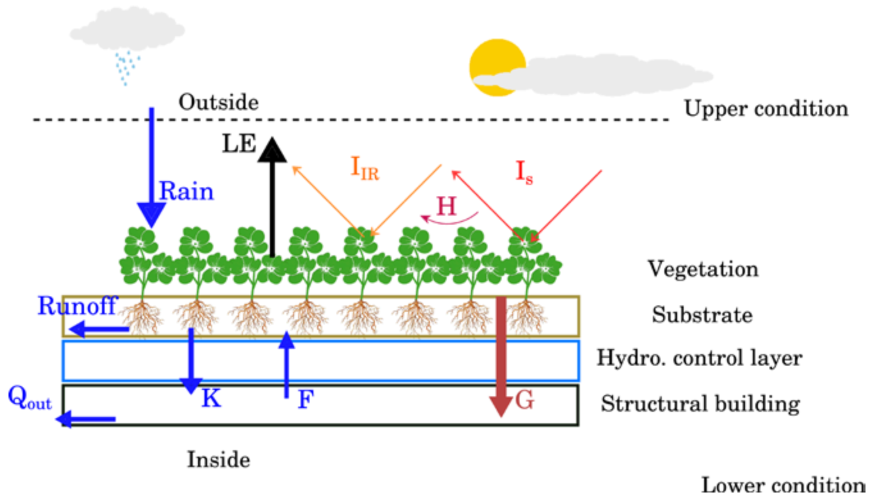

Fig. 3 : Green roof design for TEB-GREENROOF and associated physical processes adapted from [Demunck et al. 2013]. Left: hydrological processes – surface runoff(RUNOFF), vertical water fluxes (K , upward capillary action depending on moisture gradient), infiltration (K) and water drained out of the green roof base water (Q_{out}) and precipitation (RAIN) Right: energy balance terms – long and short wave radiation (I_{IR} and I_S), sensible heat flux (H), latent heat flux (LE) and ground storage heat flux (G). LE is the sum of the ground evaporation (LE_G), the evaporation of the water intercepted by the plant canopy (LE_R) and the vegetation transpiration (LE_{TR}). Top: thermal processes – within all layers, thermal conduction (G) between natural layers, GR between artificial layers.

3.3 Climate change assessment

With the impacts of the climate change announced on the increasing of the frequency of the periods of heat waves, the question of the water reserve is very fast going to arise. The water requirements of the various vegetated devices will thus be to quantify according to their nature but also to the season and some distribution of rains locally. A study of the evolution of the precipitation and the temperatures on the three target cities within the framework of a climate change will allow a better adequacy between the choice of the nature of vegetated devices, their number and their location. In this context, the use of the scenarios of the project GICC DRIAS will be relevant [gate DRIAS, *Lémond et al., 2011*].

4. Next steps

The next steps will be to validate the TEB model with the experimental results of the three platforms and see how reliable is the model to such data. In order to assess the role of VGR and its cooling effect in the future with a changing climate it will be interesting to use DRIAS model outputs as an input of TEB.

Acknowledgment

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References

Alexandri E. and Jones, P., 2008: Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*, **43(4)**.

Cunha A. D., 2009: Urbanisme végétal et agro urbanisme : la ville entre artifice et nature. *Urbia, les cahiers du développement urbain durable*, **8**.

de Munck C. S., Lemonsu A., Bouzouidja R., Masson V. and Claverie R., 2013: The GREENROOF module (v7.3) for modeling green roof hydrological and energetic performances within TEB. *Geosci. Model Dev.*, **6**.

Emelianoff C., 2007: Les quartiers durables en Europe : un tournant urbanistique. *Urbia, les cahiers du développement urbain durable*, **4**.

Emilsson T., Berndtsson J.C., Mattsson J.K. and Rolf K., 2007: Effect of using conventional and controlled release fertilizer on nutrient runoff from various vegetated roof systems. *Ecological Engineering,* **29**.

Hamdi R. and Masson V., 2008: Inclusion of a Drag Approach in the Town Energy Balance (TEB) Scheme: Offline 1D Evaluation in a Street Canyon. *J. Appl. Meteorol. Clim.*, **47**.

Lémond J., Dandin P., Planton S., Vautard R., Pagé C., Déqué M., Franchistéguy L., Geindre S., Kerdoncuff M., Li L., Moisselin J.-M., Noël T. and Tourre Y.M., 2011: DRIAS: a step toward Climate Services in France. *Adv. Sci. Res*, **6**.

MacIvor J. S and Lundholm J., 2011: Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate. *Ecological Engineering*, **37**.

Masson V., 2000: A physically-based scheme for the urban energy budget in atmospheric models. *Boundary-Layer Meteor*., **94**.

Masson V., Moigne P. L., Martin E., Faroux S., Alias A., Alkama R., Belamari S., Barbu, A., Boone A., Bouyssel F., Brousseau, P., Brun, E., Calvet, J.-C., Carrer, D., Decharme, B., Delire, C., Donier, S., Essaouini, K., Gibelin, A.-L., Giordani, H., Habets, F., Jidane, M., Kerdraon, G., Kourzeneva, E., Lafaysse, M., Lafont, S., Lebeaupin-Brossier, C., Lemonsu, A., Mahfouf, J.-F., Marguinaud, P., Mokhtari, M., Morin, S., Pigeon, G., Salgado, R., Seity, Y., Taillefer, F., Tanguy G., Tulet P., Vincendon B., Vionnet V.,and Voldoir A., 2013: The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variable and fluxes. *Geosci. Model Dev.*, **6**.

Reicosky D.C. and Peters, D.B., 1977: A Portable Chamber for Rapid Evapotranspiration Measurements on Field Plots. *Agron J.*, **69**.

Santamouris M., 2012: Cooling the cities: A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*, **103**.

Stannard, D.I. and Weltz M.A., 2006: Partitioning evapotranspiration in sparsely vegetated rangeland using a portable chamber. *Water Resour. Res*. **42**.

Steduto, P., Çetinkökü Ö., Albrizio R. and Kanber R., 2002: Automated closed-system canopy-chamber for continuous field-crop monitoring of CO2 and H2O fluxes. *Agricultural and Forest Meteorology*, **111**.

Takebayashi H. and Moriyama M., 2007: Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. *Building and Environment*, **42(8)**.

Teemusk A. and Mander U., 2007: Rainwater runoff quantity and quality performance from a green roof: the effects of short-term events. *Ecological Engineering*, **30**.

Wong N.H., Cheong D.K.W., Yan H., Soh J., Ong C.L. and Sia A., 2003: The effects of rooftop garden on energy consumption of a commercial building in Singapore. *Energy and Buildings*, **35**.