The heat storage system of Kuujjuaq greenhouse

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1 Context

Greenhouse building in isolated northern communities is booming. Indeed, vegetables cultivation within community greenhouses bring several benefits [1, 2]. Among them, we can quote an improved access to fresh vegetables leading to a rising in their consumption or the possibility to educate children to gardening. Having a collective place to garden is also an asset to meet other people and to develop the sense of belonging to the community.

However, cultivation in northern greenhouses faces two challenges: a large temperature gap between day and night when plants are growing, in summer (cf 2.2), and the duration of the growing season which is often short. For example, this season is 4.5 months in the Kuujjuaq community greenhouses and 4 months in Inuvik [3] or Iqaluit [4]. The short season is due to a lack of insulation, and few means of heating or excess heat storage. Indeed, northern greenhouses are often imported from South, without specific adaptations.

In order to meet these challenges of the great temperature amplitude and the short growing season, a research team composed of French and Quebecker researchers [1] set up a project to understand the thermal behavior of greenhouses and the possible improvements: the Siqiniq (or Seqineq) project [5] (Siqiniq means sun in Inuktitut, one of the Inuit languages). This project is carried by the OHMI Nunavik [6], a research program interested in links between humans and their ecosystem. Thus, a collaboration with the Northern Village (NV) of Kuujjuaq began in 2016 on the greenhouses of the village.

2 Kuujjuaq greenhouses

2.1 Characteristics

Kuujjuaq is a village of Nunavik, the northern territory of the province of Quebec located above the 55th parallel north. Two greenhouses were built in this village, one in 1999 (called "the old greenhouse"), the other in 2012 (called "the new greenhouse") (Figure 1).

Figure 1: Kuujjuaq greenhouses, the new one at the left, the old one at the right

Figure 2: Opening of the new greenhouse roof

[1] Project researchers are from Pau University (UPPA, France), Ecole de Technologie Supérieure (ETS, Montréal) and Institut National de la Recherche scientifique (INRS, Québec).

Each greenhouse has a surface of 1500 sq. ft. (140 m^2) and an envelop composed of double panels of polycarbonate. Both of the greenhouses are equipped with automatic ventilation, to prevent too high temperature for the plants during long sunny periods. This ventilation works in two sequences: first a fan blows the hot air to the outside, then, if the heat remains too high, a part of the roof is opened (Figure 2)

These community greenhouses are divided in 48 gardening plots. Each greenhouse member who has a plot can grow whatever he wants to. The cultivated vegetables are mainly green leaf vegetables (lettuce, bok choy, spinach, kale) but also radish, potato and carrot. In 2016 more than one ton of vegetables has been harvested within the two greenhouses [7]. These vegetables are cultivated in a soil specially imported from South. The growing season of Kuujjuaq greenhouses is 4.5 months, from mid-May to the end of September.

2.2 Analysis of the thermal behavior of the new greenhouse

In order to understand the thermal behavior of the greenhouse, the project team set up sensors in the greenhouse during several instrumentation campaign. The measuring tools include an outside thermometer, several thermometers inside the new greenhouse and a pyranometer (a device measuring the solar flux). Data have been collected for more than two years. The data analysis allowed to find much interesting information.

First of all, the study of the solar flux showed that Kuujjuaq has a great solar potential, notably in early spring. We can see this potential on figure 3 where the monthly insolation of Kuujjuaq and Toulouse (a city in the South of France) are compared. The great solar energy received by Kuujjuaq at the spring and summer is due to the fact that the more you move away from the equator, the longer the summers are and the shorter the winter days are. We can't see that in June and July on figure 3 because of a cloudy summer in Kuujjuaq.

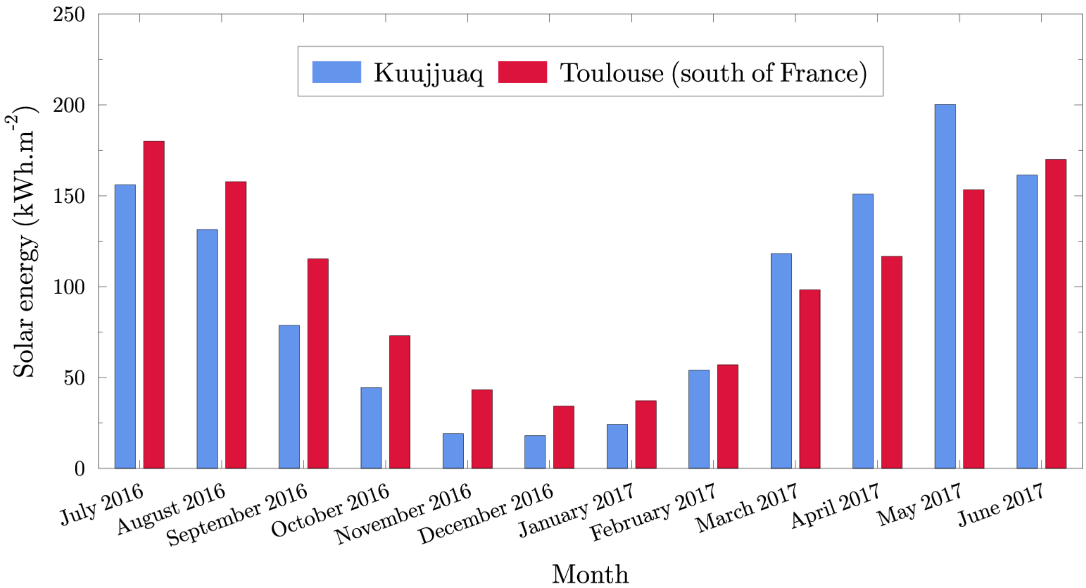

Figure 3: Monthly insolation in Kuujjuaq and Toulouse

Then, the study of the temperature data spotlighted a great temperature difference between day and night. For example, the recordings made at the beginning of July

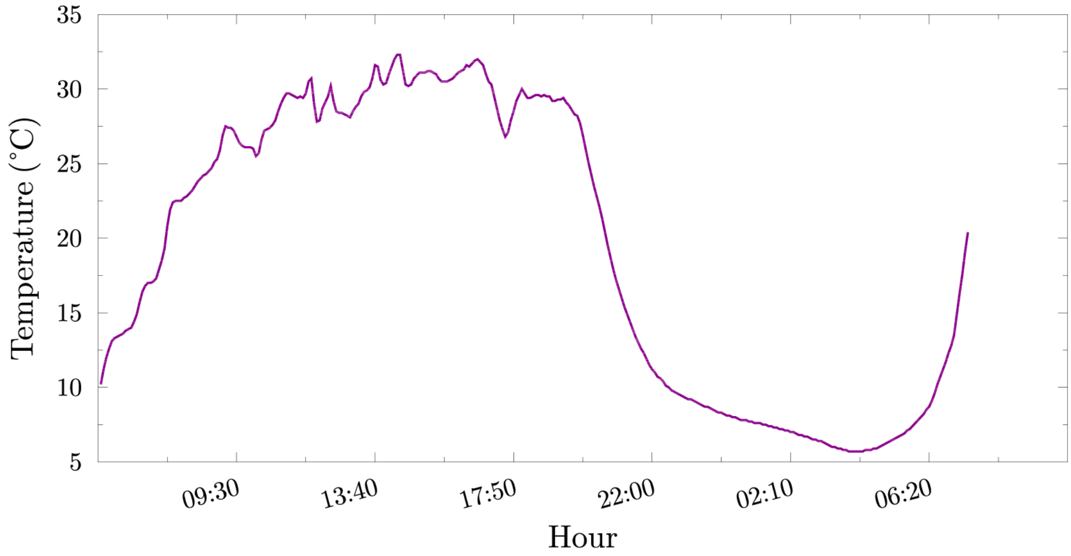

Figure 4: New greenhouse inside temperature between the 5^{th} and the 6^{th} of July

show that it is very hot inside the greenhouse during the day (above 30 °C) but that the temperature can drops to 5 °C during the night (Figure 4). This great temperature gap induces a stress for the plants and can stop their growing phase if it is too cold. This phenomenon of large temperature drop between day and night is also present at the beginning of the growing season, with night frost inside the greenhouse, preventing the season from beginning earlier. Indeed, the plants need a positive (minimal) soil and air temperature to be sowed.

3 The heat storage system

3.1 Utility and functional principle

One way to avoid to have too low temperature by night would be to set up a heating system. However, such a set-up would be expensive, from a financial and energy perspective. Indeed, it should not only pay for the system itself but also the energy to run, diesel or electricity, year after year.

Yet, we saw that Kuujjuaq has a great solar potential during spring and summer, to such an extent that the greenhouse temperature is too high during the day. So the idea has been to store this surplus heat to return it by night (Figure 5). It is the principle of the thermal mass. The Northern Village (NV) of Kuujjuaq being aware of the problem of the gap temperature, a collaboration between the NV, the Kativik Regional Government (KRG) and the research team began, to build such a storage system.

3.2 Building of the storage system

The realization of the storage system began in mid-October 2019 and lasted a month. The project was funded by the Société du Plan Nord, and was realized in close collaboration with the KRG. The materials used most often to store the heat are the water and the

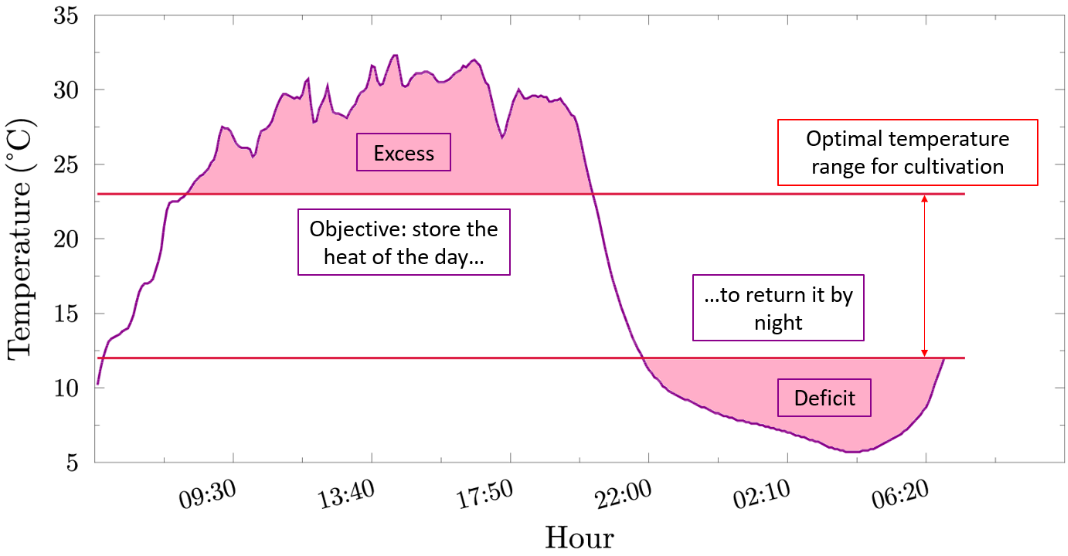

Figure 5: Storage functional principle

Figure 6: Inside of the new greenhouse after works

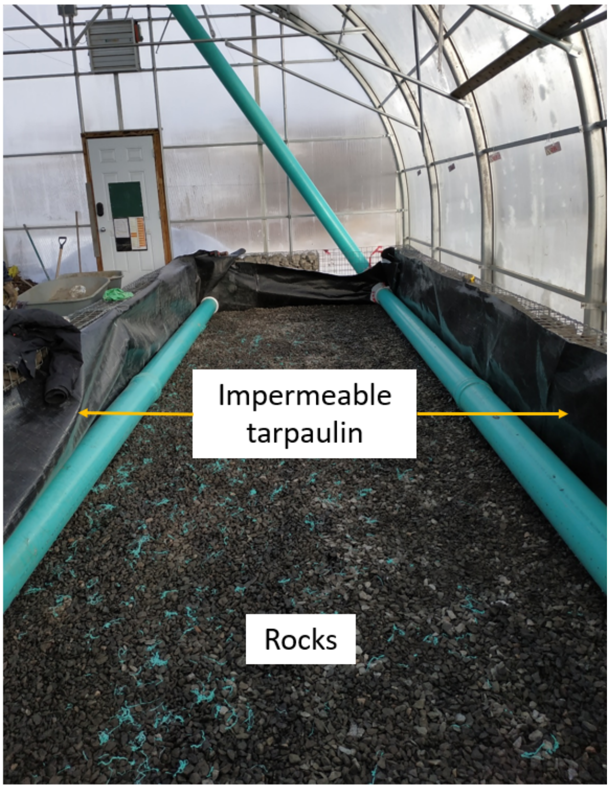

Figure 7: Photo of a rock bed under construction

rock. Rocks were chosen because they are easier to set up, there is no risk of leakage and a freeze of the storage system is avoided during winter.

This storage system includes three elements: a concrete slab at the center of the greenhouse, rocks between 2 in and 8 in (5 cm and 20 cm) contained in gabions (steel grid, Figure 6) and rock beds (also called caissons) set up under the growing soil. The concrete slab and the gabions are a passive storage system: they accumulate and return the heat naturally. The rock bed system is more complex: air is blown inside caissons, by means of fans and pipes system. The greenhouse was divided in 4 parts, with a rock bed for each part. Each caisson has an area of 235 sq. ft. (22 m^2) and a height of 1 ft (30 cm). They are filled with small rocks measuring between 0.75 in and 2 in (2 cm and 5 cm). These rocks are wrapped in an impermeable tarpaulin (Figure 7), which is insulated from the ground with Styrofoam. The caissons are equipped with a system of drilled pipes and a fan to ensure an air flux within the rocks. This system is showed for one caisson on figure 8.

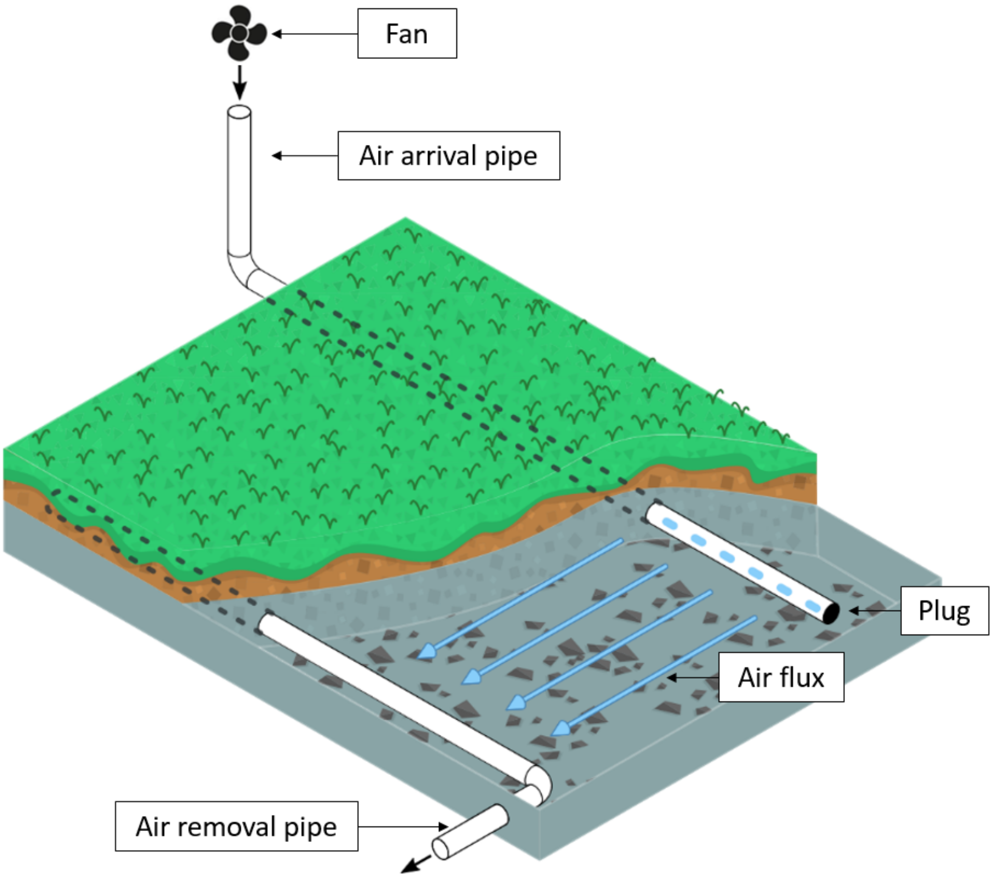

Figure 8: Functional schematic of a rock bed

During the day, the hot air of the greenhouse will be blown into the colder rocks of the caisson (instead of being thrown outside), allowing to lower the greenhouse temperature and increase the rocks temperature: it is the charge phase. By night, the cold air of the greenhouse will be blown within the rocks heated up during the day in order to raise the greenhouse air temperature: it is the discharge phase.

3.3 Prospects

The storage system was built in the new greenhouse during the 2018 fall but has not been tested yet. It will be run at the beginning of the 2019 growing season. Several temperature sensors have been set up within the bed rocks during their construction. Data will be collected through the growing season in order to assess the storage system performance at the 2019 fall. Depending on the data assessment, improvements could be planned to build a similar system in the old greenhouse.

References

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