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Making the most of Parisian quarries' air

Experimental climatic furniture using Parisian quarries' air to cool public spaces.

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Abstract. *As many large cities are confronted with global warming, Paris is looking for ways to be more resilient when facing urban heat island. The article describes a design experimentation aiming at tapping into naturally fresh air resources located in underground quarries underneath the streets of Paris. Working as urban sized earth-to-air-heat-exchangers, underground galleries will fuel a climatic bench that will cool down public spaces in summer.*

Keywords: *urban heat island, Paris, underground quarry, urban furniture, public space*

Short term actions for more livable public spaces during heat waves

After the deadly heat wave of 2003 that caused 15,000 excess deaths in France¹, protecting citizens from extreme climatic phenomena became a health matter that had led to implementing a "heat wave emergency plan" on a national scale. On a local level, cities are looking for ways to become more resilient when facing more intense and longer heat waves in summer. In this regard, the historical, highly mineral urban fabric of Paris makes the city more prone to suffer from urban heat island that causes denser neighborhoods to be up to 4°C hotter than less dense parts of the city², thus worsening living conditions when such events occur. While long term solutions at the urban level are being implemented by Paris officials to reduce urban heat island, short term actions are also needed to address the yearly recurring phenomenon of hotter summers. In attempting such things, looking for naturally renewable sources of freshness within the denser parts of the city becomes necessary.

Under most of Paris's left bank lies a large network of underground quarries. At a depth of between 15 and 25m underground, the intricate galleries add up to over 225km in length. In this underground environment, temperatures remain around 14°C all year and

¹ Official number given by the French authorities, "Canicules : effets sur la mortalité en France métropolitaine de 1970 à 2013, et focus sur les étés 2006 et 2015." Accessed 20 June 2020. <https://www.santepubliquefrance.fr>.

² According to studies lead by Parisian authorities and compiled in Agence Parisienne du Climat. *L'îlot de chaleur urbain à Paris, un micro climat au cœur de la ville*. Agence Parisienne du Climat, Météo France, Paris: Agence Parisienne du Climat, 2018.

constitute a large reservoir of unused fresh air. Parisian underground quarries are usually seen as a hazard because they weaken building grounds. A special quarries inspection bureau (Inspection Générale des Carrières, or IGC) manages the risk they pose. Looking at them as a potential resource of freshness therefore constitutes a way to benefit from a historically significant feature to address a contemporary issue, but also contributes to making Parisians more conscious of what lies beneath Paris' streets.

The effects of climatic furniture on the surrounding atmosphere

Conscious of this untapped resource, the Paris based architecture design studio ALT and designers Emma Lelong and Remi Nguyen proposed a climatic furniture to cool down Parisian public spaces. The design won a call for projects launched by the city of Paris and the Pavillon de l'Arsenal³. The proposal attracted the attention of Climespace⁴ that offered its technical support by funding a study by Elioth⁵.

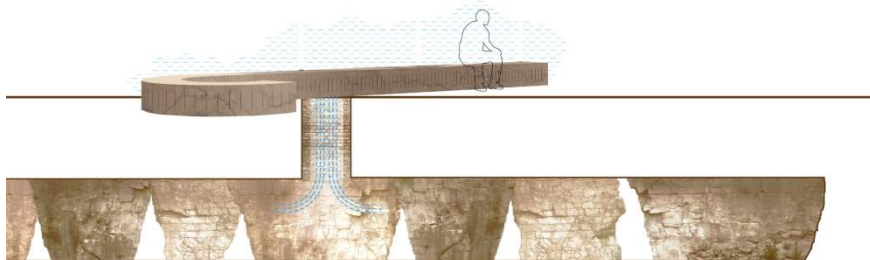


Figure 1. Cross section of the proposed climatic furniture, ALT, Emma Lelong, Rémi Nguyen, 2018

The design needed to take two aspects into account. On one hand, the shape and the location of the furniture needs to enable users to take long pauses on it in order to cool their body down and alleviate the stress induced by prolonged periods of overheating. The furniture, was therefore designed as a large bench where many people could rest and it was decided that it should be located in a public space that is comfortable enough to welcome long stays. On the other hand, the furniture cools the atmosphere around it by design. The bench will then behave in accordance with the outside climatic condition to create a more welcoming atmosphere around it. In summer, when the temperature exceeds 28°C, the bench will start blowing a cool breeze. Designing this new atmosphere required taking into consideration every aspect of the user's experience and four ways for the bench to interact with people nearby have been clearly identified.

³ A Parisian Museum dedicated to architecture.

⁴ The urban cooling network managing company in Paris.

⁵ A Paris based engineering studio.

Firstly, a cooling effect will result from the fact that air around 14°C and 17°C will be blown by the bench. This temperature may vary according to the depth of the gallery and the air flow through the underground network. Secondly, the air movement itself will accelerate evaporation of perspiration on the skin, providing a cooling sensation. However, a strong breeze may cause discomfort. An optimum airflow of 500m³/h has been calibrated from the amount of fresh air available in quarries and the pace at which it naturally renews. Thirdly, because the underground air is water saturated with a hygrometry reaching 100%, the pulsed air will contain droplets that will act as a humidifier, a cooling system largely sought after during Paris summers that also coincides with dryer episodes. Finally, the bench will be made of marble stone from the Seine valley. Its thermal effusivity is around 2500 J.K⁻¹.m⁻².s^{0.5}, making it more efficient to exchange thermal energy with its surroundings, thus making it naturally cool to the touch.

The impact of the bench on the surrounding atmosphere was modeled using Physiological Equivalent Temperature index (PET) which describes the heat exchange between the body and the environment (Hoeppel, 1999). The PET index has, for instance, been used to create a bioclimatic map of urban heat islands (Matzarakis, Mayer, Iziomon, 1999). Taking into consideration the aforementioned effect of the bench on the nearby atmosphere, the model showed that the PET index could be improved by 10°C compared to the referential temperature when the bench is functioning in optimal conditions.

From modelling to empirical testing

Although the model approach was necessary to design some key elements of the bench such as the air flow, the maximum length of the bench and the impact on the nearby atmosphere, many aspects of its efficiency can only be explored and tested with an empirical approach. Through the design process the first step was to work in collaboration with the quarries inspection bureau (IGC) in order to quantify and qualify the air resource in galleries. Very little was known about underground air quality, its temperature and its movement throughout the network. Data was collected by exploring the network and made the modelling more precise.

Today, the high hygrometry creates a fungi rich environment which can decay limestone walls and aggravates risks of collapse. It appeared that inducing air flow bringing heat and reducing humidity might have a positive impact on the health of the underground structures. However, as these aspects are hardly studied in this environment, there is also the risk of disturbing the equilibrium. Installing a prototype becomes necessary to measure the impact of air flow on a small portion of galleries before a larger deployment is engaged. Prototyping the bench will also be an opportunity to better understand how air moves in galleries and how long it needs to remain underground to reach 14°C.

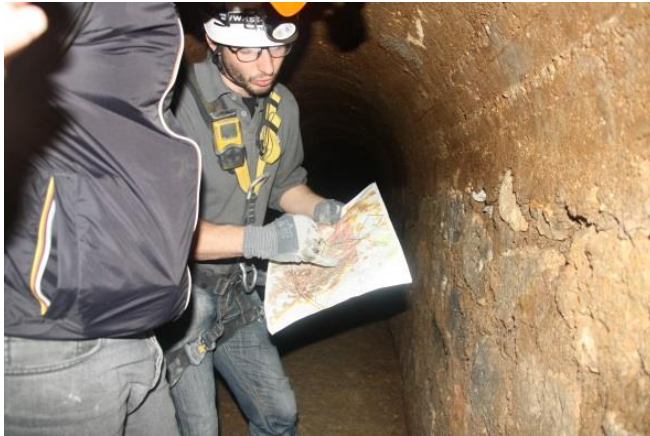


Figure 2. Underground data collection, Rémi Nguyen, 2019

Connecting underground galleries to the public space is possible with little work by using one of the 264 maintenance wells that are scattered around the city. They are around 1.5m wide and are recognizable by the IGC inscription on the manhole cover. To identify the test sites, maintenance wells location was crossed with the Parisian urban heat island map made by the city. 20 usable wells were located in the parts of the city that are the hardest hit during heat wave. The design team working alongside the Paris street management bureau (direction de la voirie et des déplacements), the location of each of the wells was studied to determine if implementing a climatic bench there could benefit local population through five criteria: who manages the public space, how much space is available to not disturb other urban uses, who uses those public spaces, how busy it is, how visible it is.

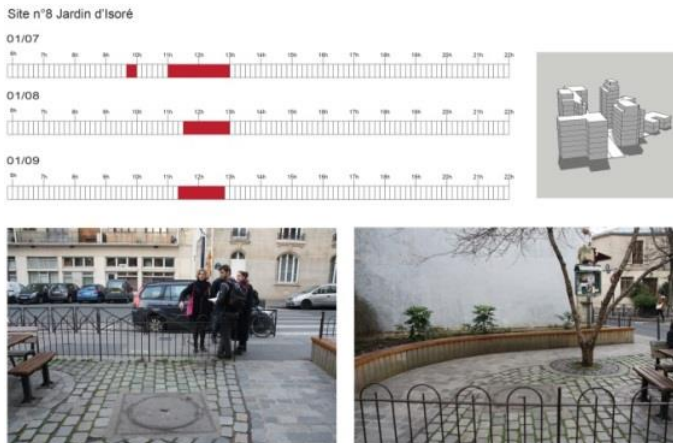


Figure 3. Implementation site study, ALT, 2019

Four sites were selected and then further studied to model their behavior during summer more precisely, mainly through sunlight exposure. More data would be needed to further understand the relation between the bench and the air flow at the scale of the neighborhood, mainly regarding thermic winds that appear during summer evening when hot air ascends creating depression at ground level. However, data on thermic wind is still scarce and could not be taken into consideration in this study⁶.

Prototyping and evaluation

While location sites were investigated, the design of the bench was also developed so it could be adapted to more than one location. Even though it is a technically complex furniture, the main purpose was to create the entirety of the bench out of a single material, marble stone, to serve as a reminder of the underground origin of the air flowing from it. Furthermore, the design needed to be adaptable to fit many urban situations. Therefore, the bench is conceived out of trapezoidal modules that can be aligned along staggered rows to create a straight line or along the same direction to create a curve. The air flows without any metal sheath through a cavity hollowed in the module. The air flows out through slot created by spacers that are included in the design of the modules. This intricate design could only be numerically carved out to make them from one stone block. Working with a Parisian stone carver, Heres, who was equipped with numerical carving tools, made it possible to test the design and the comfort it will provide.



Figure 4. Prototype made by Heres, ALT, Ema Lelong, Rémi Nguyen, 2019

Prototypes of a few modules have been built, and today the first scale one test is ready to start. However, the Covid-19 epidemic has made it impossible to undergo the teste in Paris streets this year, for it is still unsafe to gather in public spaces. Moreover, creating air flow could increase the risk of person-to-person transmission of airborne diseases.

⁶ The city of Paris has some public data on thermic wind in summer. APUR. *Les îlots de chaleur urbain du cœur de l'agglomération parisienne. Cahier#3 : brises thermiques*. APUR, Paris: APUR, 2017.

Testing has therefore been put on hold for the 2020 summer but should resume in 2021. The scale one prototype aims to measure the actual impact on refreshing the space around the bench regarding the PET index that was used to model the behavior of the bench. The office ALT will also document new uses that could be induced in the public space around the bench. Those ground level observations lean on similar experiences led by the city of Paris with their program of "oasis courtyard" in elementary schools⁷ that combine climatic measure with socio anthropological observations. Underground level evaluation will also be necessary, firstly to measure how fast the fresh air resource naturally renews itself and then to better understand how hot air flows impact underground fungal environments. Air quality measurements will also be taken in order to ensure that no pollution is pulsed in the streets. The evaluation aims to verify if such furniture should be deployed at a larger scale in the streets of Paris, since other sites could be used for similar interventions. Yet, identical actions are only possible in places where underground quarries are present making it necessary to explore other types of underground cavities that could fuel comparable apparatus in parts of the city with no underground quarries. Many do exist, but the quality and quantity of their resource in fresh air needs to be thoroughly investigated case by case. Such actions are useful to help fight the effects of warmer summers until the city's urban fabric undergoes more structural changes to fight urban heat islands.

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⁷ Oasis courtyard is a test program aimed at creating cooler spaces inside school courtyard. CAUE 75. "Retour sur une année de projet cours oasis." Online event, CAUE75, Paris, Accessed June 02 2020. <https://www.caue75.fr>.