Thermal measurement campaign in three streets of Strasbourg to study interactions between trees and facades

Vincent LECOMTE[1*], Hélène MACHER[1], Tania LANDES[1], Françoise NERRY[2], Renato CIFUENTES[2], Pierre KASTENDEUCH[3], Georges NAJJAR[3], Chaimaa DELASSE[1,4]

[1]Université de Strasbourg, INSA Strasbourg, 24 Boulevard de la Victoire, 67000 Strasbourg, France, CNRS, Laboratoire ICUBE UMR 7357, Equipe TRIO
[2]Université de Strasbourg, CNRS, ICUBE UMR 7357, Equipes TRIO, RDH and IMAGeS, 300 Boulevard Sébastien Brant, 67412 Illkirch, France
[3]Université de Strasbourg, CNRS, Faculté de Géographie et d'Aménagement, 3 Rue de l'Argonne, 67000 Strasbourg, France, Laboratoire ICUBE UMR 7357, Equipe TRIO
[4]Ecole des Sciences Géomatiques et de l'Ingénierie Topographique, Institut Agronomique et Vétérinaire Hassan II, Madinat Al Irfane, Avenue Allal El Fassi, 6202 Rabat, Maroc
[*](corresponding author: vincent.lecomte@insa-strasbourg.fr)

Abstract - The TIR4sTREEt project focuses on urban climatology in Strasbourg. Its aim is to study the behaviour of urban trees and their cooling effect during heat waves. Microclimatic, eco-physiological and 3D data have been collected for this analysis. Thermal measurements were also carried out. On the one hand, thermal infrared cameras were installed on fixed structures and mounted on a mobile system to monitor canopy temperatures and the impact of tree shading on facades during several weeks. On the other hand, thermo buttons were placed on facades. This paper presents the thermal measurement campaign and the first comparison of data. In future works, these comparisons will enable us to better understand and therefore to predict the interactions between trees and facades.

1. Introduction

Urban climatology is a broad field of study that encompasses a wide range of phenomena at different scales, ranging from the city to the street. The study area of our project TIR4sTREEt is located in Strasbourg along three streets (Figure 1). Each street is planted with trees of three different species (lime, plane and hackberry trees). The objective of this project is to investigate the cooling effect of trees on the urban microclimate in order to mitigate the formation of urban heat islands. In accordance with this, this study investigates the interaction between trees and facades, in particular regarding surface temperatures, using infrared thermography.

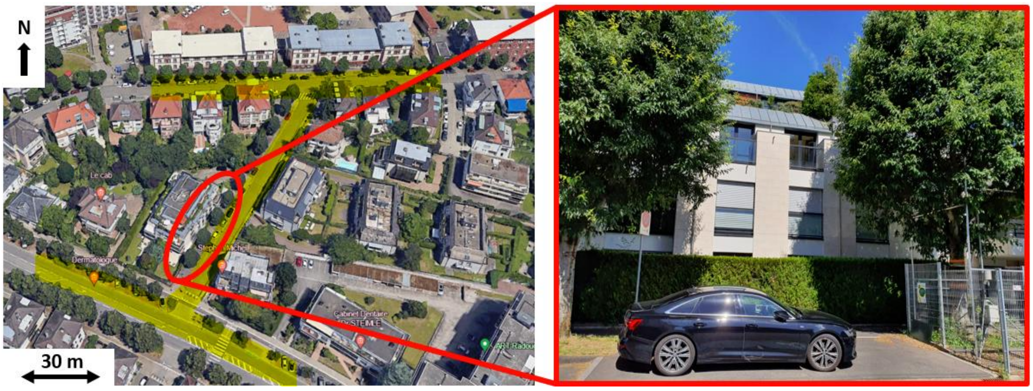


Figure 1: *Study area in Strasbourg (left) and the main facade under study (right). The three streets are highlighted in yellow (Source: Google Earth)*

https://doi.org/10.25855/SFT2024-079

Numerous microclimatic and eco-physiological sensors were installed in the streets and on the trees. In addition, several thermal sensors have been installed to highlight the interaction between trees and facades. Thermal InfraRed (TIR) cameras can provide thermal images of a scene, aiding in the interpretation and analysis of the impact of tree shading on facades. These images will also be used to validate microclimatic simulation software such as LASER/F (*LAtent SEnsible Radiation Fluxes*) [1] and LASER·T (*LAtent SEnsible Radiation & Trees*) [2].

This paper describes the thermal measurements campaign. Firstly, the state of the art of street scale thermal measurements will be presented. Then, the thermal sensors used during our campaign will be described. Next, data acquisition protocols will be explained. Finally, various methods for processing and utilizing thermal data to facilitate comparison and validation will be outlined.

2. Related works

In urban environments, infrared thermography is a useful tool for studying buildings and trees. This technology has been utilised to monitor changes in canopy temperature and correlate them with meteorological, physiological, and urban factors [3]. It can also be used to estimate the thermal stress of trees [4]. When applied to buildings, thermal imagery can be used for energy studies [5].

TIR cameras are handheld systems that can be used manually from the ground or mounted on mobile systems. It can be installed on a car [6] or on a simple trolley with additional microclimatic sensors to study the thermal comfort of a street [7].

More specifically, TIR cameras can be used to study the relationship between trees and facades. In [8], a campaign was conducted to obtain thermal infrared images of an urban park in Strasbourg. The authors captured TIR images of a building facade and the surrounding trees every 5 minutes during 51 hours. Additionally, a LASER/F simulation was performed to compare collected and simulated infrared measurements. A study on the interaction between trees and facades is presented in [9], based on a miniature street model using concrete blocks and testing various tree arrangements and shapes with plastic tree scale models. To analyse the impact of tree shadows on facades, several thermo buttons were placed on the concrete blocks, and TIR images were acquired. It is important to note that the measurements were carried out on a miniature model and plastic trees. Therefore, their eco-physiological effects were not taken into consideration.

As a complement to field measurements, simulations can also be conducted to analyse the impact of trees in urban areas in order to reduce the effect of urban heat islands. In particular, a 3D mock-up can be useful to determine optimal shadowing scenarios. For instance, it can help identify the optimal location for trees near dwellings to maximise shade and enhance indoor comfort [10]. For outdoor thermal comfort, it is also possible to simulate the shadows of buildings and trees on facades to refine the results of land surface temperature calculations [11]. This allows the testing of different scenarios, such as tree growth and planting, to reduce heat in the street or neighbourhood.

3. Specifications of thermal sensors

For this study, several thermal infrared cameras were used, either fixed or mounted on a mobile system. To complement and compare the temperature measurements acquired, several thermo buttons were also placed on the facade of a building. Both datasets will be compared.

3.1. Thermal cameras

The FLIR T560 (Figure 2a) is a thermal camera equipped with a thermal infrared sensor and a RGB (Red, Green, Blue) sensor. The thermal camera measures the surface temperatures of the target elements. RGB information is very useful to help the user analyse the corresponding thermal image. The FLIR TAU 2 (Figure 2b) and FLIR A655sc (Figure 2c) are also thermal cameras, but unlike the T560, they do not have a RGB sensor. Their main features are listed in Tables 1 and 2.

(a) (b) (c)

Figure 2: *Thermal cameras used during the campaign;*
(a) FLIR T560 ; (b) FLIR TAU 2 ; (c) FLIR A655sc

	Focal length	*Detector pitch*	*Field of view*	*Image resolution*
	mm	µm	°	pixels
FLIR T560 TIR sensor	9,7	12	42 x 32	640 x 480
FLIR TAU 2	13	17	45 x 37	640 x 512
FLIR A655sc	24,6	17	25 x 19	640 x 480

Table 1: *Optical specifications of TIR camera T560, TAU 2 and A655sc*

	Sensor	*Spectral range*	*Thermal range*	*Thermal resolution*	*Thermal accuracy*
		µm	°C	mK	°C
FLIR T560 TIR sensor	Uncooled microbolometer	7,5 - 14	-20 to 120	<30 at 30°C	2
FLIR TAU 2	Uncooled microbolometer	7,5 – 13,5	-25 to 100	-	-
FLIR A655sc	Uncooled microbolometer	7,5 - 14	-40 to 150	<30	2

Table 2: *Thermal specifications of TIR camera T560, TAU 2 and A655sc*

3.2. Thermo buttons

A thermo button is a miniature temperature data logger (Figure 5) which measures a surface temperature at a specific point and can be placed directly on the surface. The thermal accuracy is 0,5 °C and the resolution can be set to 0,1 or 0,5 °C allowing to store 4096 and 8192 measurements respectively, providing an autonomy of approximately 42 and 84 days respectively. This sensor is very easy to set up, it has an interesting thermal accuracy compared to TIR cameras, and its diameter measures just over a centimetre. However, it does not allow downloading or tracking of measurements during the acquisition period. Hence, the data must be retrieved once the measurements have been completed.

4. Data acquisition protocol

Thermal data acquisition was achieved in two ways: from fixed positions and from a mobile system. Measurements were mainly taken between July and November 2023, covering the summer heat waves as well as the cooler periods of the seasonal change.

4.1. Sensors in fixed positions

The main scene of the study area is a facade of a residential building located at 5 Ellenhard street in Strasbourg and the nearby hackberry trees (*Celtis australis*). The facade is oriented towards the East-South-East direction. Two thermal cameras have been fixed on top of a mast and a third next to the tree. The former two focused on the facade and the trees from the opposite sidewalk, the latter focused on the tree crown (Figure 6). Thermo buttons were installed on the same facade, to collect spot measurements of surface temperature. The positions of the cameras as well as that of the thermo button have been chosen to enable the observation of the interaction between the trees and the facade (Figure 6).

Figure 5: *A thermo button*

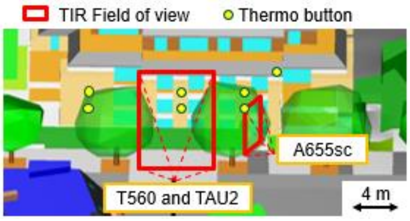


Figure 6: *Position and orientation of the sensors presented on a 3D virtual scene*

4.1.1. Thermal infrared acquisitions

In order to cover the scene as explained previously, a temporary metal structure was installed around one of the hackberry trees and a temporary mast was erected on the opposite pavement to house not only thermal cameras but also various weather sensors.

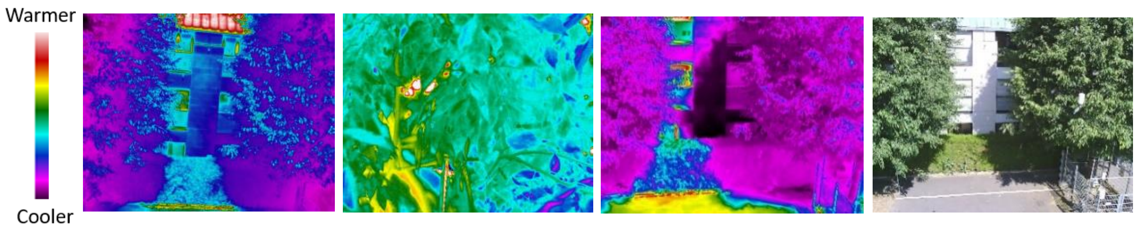
Due to the unsuitability of the installed cameras for outdoor use, certain constraints had to be considered. Firstly, the boxes housing the cameras had to be waterproof and securely mounted to withstand summer storms. A protective insulating film was necessary to shield them from high temperatures. In addition, to protect the sensors from vandalism, they were placed at the top of the mast and a security cage was installed around the tree. Finally, the cameras needed to be powered for long periods of recording. High-capacity batteries and solar panels were installed and electrical connections were adapted to overcome the problem of voltage differences between the devices.

A total of three TIR cameras were used, namely FLIR T560, FLIR TAU 2 and FLIR A655sc. Various details on the acquisition of images with these cameras are given in Table 3.

TIR camera	*Acquisition period (2023)*	*Measurement frequency*	*Location*	*Objects of interest*	*Number of images*
FLIR T560	07/07 to 24/07	5 minutes	Mast	Facade and foliage	5 005 pairs (RGB +TIR)
FLIR TAU 2	03/08 to 16/11	5 min 20 sec	Mast	Facade and foliage	21 210
FLIR A655sc	07/07 to 23/10	1 minute	Metallic structure	Foliage only	121 717

Table 3: *Details on the thermal acquisition using three cameras*

The environmental acquisition parameters were set arbitrarily before the cameras were installed. These parameters will be used later to radiometrically correct the TIR images. In addition, as the emissivity of the materials of the observed scene elements are different and unknown, it was set to 1 to obtain brightness temperatures. Finally, images were regularly retrieved via Bluetooth for the FLIR T560 and directly via a connected laptop for the FLIR A655sc. However, for the FLIR TAU 2, data was only retrieved at the end of the acquisition period as it did not have on-site data transfer capabilities. Examples of TIR images from each camera can be seen in Figure 7.



(a) (b) (c) (d)

Figure 7: *TIR images from the FLIR TAU 2 (a), FLIR A655sc (b), FLIR T560 (c) and its corresponding RGB photo (d) taken in Ellenhard street*

4.1.2. Thermo buttons

Before using the thermo buttons in an experimental setup, their temperature measurements were compared with indoor measurements taken with the FLIR T560 camera. After noting the consistency of the results, several types of attachment solutions were tested to observe their influence on the measurements. The adhesive tape solution was selected.

From the 18th of July to the 29th of August 2023, seven thermo buttons were placed on the facade under study (Figure 8), programmed with a sampling frequency of 15 minutes, and a thermal resolution of 0,1 °C.

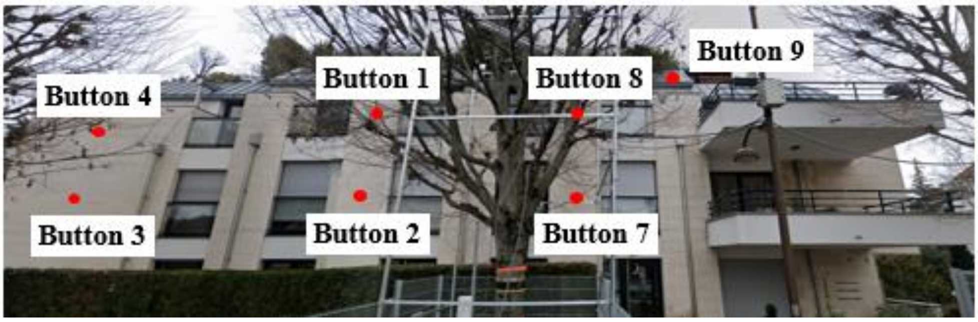


Figure 8: *Location of thermo buttons on the facade (Google Maps photo, taken during wintertime).*

The lighting conditions for the different thermo buttons on the facade are given in Table 4. In mid-July, after 3pm (UTC+2), the facade moves into the shade. This time is given as an example, as it varies throughout the summer.

Thermo button	*Lighting condition*	
	Before 3 pm	*After 3 pm*
1 and 2	Shaded by the tree then sunny	Shaded
3 and 4	Sunny	Shaded
7 and 8	Shaded by trees	Shaded

Table 4: *Lighting conditions over the thermo buttons for a day in mid-July*

We also placed two thermo buttons (thermo buttons 5 and 6) on the facade of a building located on the other side of the road, where no trees are present. They were fixed on two different facade claddings. The facade is oriented towards the West-North-West direction.

In total, three TIR cameras and nine thermo buttons collected data throughout the summer, always covering the same scene. Next section presents thermal data collected from a mobile system.

4.2. Acquisition of TIR images with a mobile system

A mobile system has been specifically designed to take measurements throughout the study area on hot and sunny days after the 24th of July. It consists of two GoPro cameras and the FLIR T560 thermal camera mounted on a telescopic tripod in a mobile cart (Figure 9).

The sensors are approximately 2 m above the ground. Acquisition has been performed in stop and go mode, with measurements taken every 30 seconds. Minimal overlap between TIR images was ensured via an iPad that streams the screen of the thermal camera.

Acquisitions were carried out using this system during heatwave periods, more particularly on sunny days, when sunshine levels exceeded 80 % throughout the day. Measurements were taken at three specific times of the day: at sunrise, culmination of the sun and sunset. At sunrise, the energy absorbed by the street is minimum since it has been released during the night; at sun's culmination the radiation is maximum; and at sunset the energy stored during the day is total. For each acquisition session, two round trips were made (Figure 10). This allowed for the observation of temperatures at the tree-building interface (Figure 10 Loop 1), the part of the crown facing the street, and the facades of buildings not protected by trees (Figure 10 Loop 2).

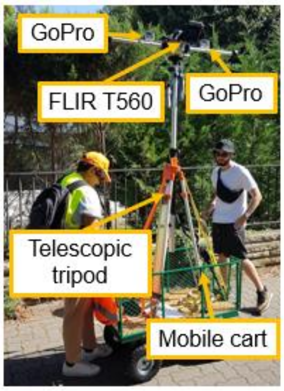


Figure 9: *Mobile system*

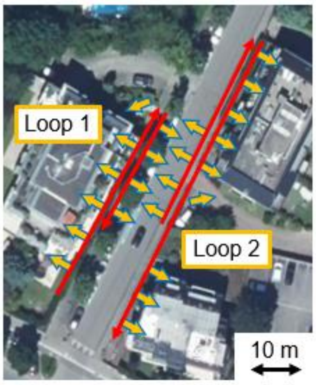


Figure 10: *Mobile system pathway*

Fixed acquisitions offer a better temporal resolution due to the automation of measurements, while mobile data allows for a wider coverage of the scene. The following section presents the data preprocessing and analysis.

5. Data preprocessing and analysis

Following the measurement campaign, and as part of preprocessing of the data, the cameras were calibrated to correct the TIR images. Secondly, a comparative analysis was performed between the temperatures extracted from the images and those measured by the thermo buttons.

5.1. Camera calibration

The cameras were calibrated radiometrically and geometrically using the method and equipment already established [12].

Radiometric calibration was performed using the Land P80P blackbody, which has a temperature accuracy of 0,1 °C at 50 °C. The temperatures recorded by the cameras were compared with those of the blackbody over a temperature range from 15 °C to 60 °C in intervals of 5 °C. Furthermore, the thermal homogeneity of the sensors was tested using the Mikron m345 blackbody at a temperature of 45 °C. This blackbody has a larger cavity than the Land P80P, which facilitates the entire coverage of the field of view of the cameras.

Geometric calibration is the process of determining the interior orientation of cameras using a test pattern. This involves calculating the coordinates of the main point and the distortion coefficients of the cameras. To achieve this, an aluminium checkerboard with black stickers was used. The emissivity difference between the materials allows the checkerboard to be viewed in thermal infrared. The camera parameters were then calculated.

5.2. Data analysis

An initial comparison of the surface temperatures measured with the FLIR T560 and the thermo button 2 was made on the facade under investigation. For the TIR images, the emissivity was arbitrarily set at 0,95, an approximate value for facade walls in Strasbourg [13], pending a more detailed study of the facade materials. The graph superimposing the two temperature curves is shown in Figure 11:

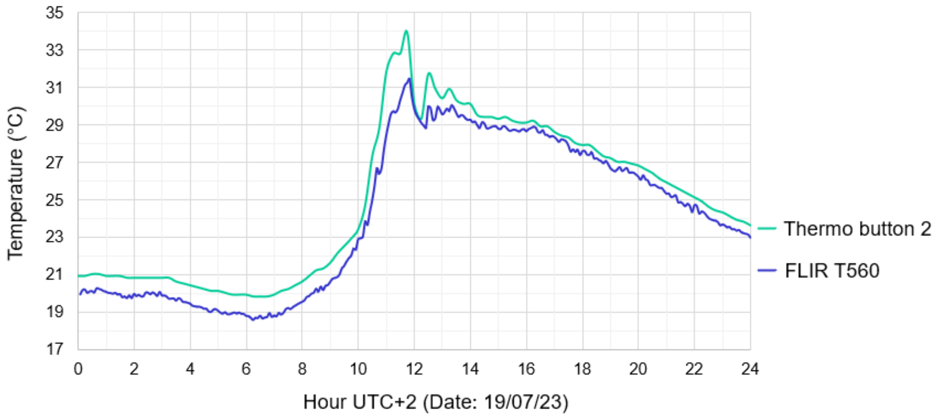


Figure 11: *Comparison of temperatures measured with the FLIR T560 and thermo button 2*

The mean deviation between the FLIR T560 and the thermo button measurements is 0,89 °C and the standard deviation reaches 0,86 °C. The deviations are not constant throughout the day. The most accentuated deviations are observed around midday when the temperature changes rapidly. Moreover, the graph suggests that the thermal camera underestimates temperatures when compared to the thermo button. These differences may be respectively attributed to the inertia of the thermo button or to the corrections applied by FLIR, which are calculated from environmental parameters that are currently set arbitrarily. Further comparisons and analyses will be conducted to refine the measurements.

6. Conclusion and future works

During the summer of 2023, a large amount of thermal data was acquired at our study site: TIR images as well as temperatures at specific points (thermo buttons). Based on this data, thorough data preprocessing and analysis have been performed to verify the reliability of the measurements.

In future work, the TIR images will be corrected radiometrically and geometrically from the parameters calculated during the camera calibration. Moreover, additional analyses will be carried out by combining thermal data with micro-climatic measurements.

Finally, 3D thermal models will be constructed at different times by texturing an accurate geometric model of the three streets with the acquired TIR images. These thermal models will be compared with the results of microclimatic simulation tools in order to refine their predictions.

References

[1] Kastendeuch, P., Najjar, G. and Ringenbach, N. (2006). Modélisation du bilan radiatif et d'énergie d'un canyon urbain à Strasbourg. *Climatologie*, Vol.3, pp25-42.

[2] Saudreau, M., Triollet, L. and Laille, P. (2021). Les résultats du programme de recherche ANR COOLTREES, une fenêtre ouverte vers l'aménagement des villes de demain. INRAE; Plante & Cité, 26 rue Jean Dixméras, 49066 Angers Cedex 01; Université de Strasbourg (Unistra), FRA.; CNRS. 2021. hal-03754282

[3] Meier, F. and Scherer, D. (2012). Spatial and temporal variability of urban tree canopy temperature during summer 2010 in Berlin, Germany. *Theoretical and Applied Climatology*. Vol.110, pp373–384

[4] Fuentes, S., Tongson, E. and Gonzalez Viejo, C. (2021). Urban Green Infrastructure Monitoring Using Remote Sensing from Integrated Visible and Thermal Infrared Cameras Mounted on a Moving Vehicle. *Sensors*. Vol.21, p295.

[5] Lucchi, E. (2018). Applications of the infrared thermography in the energy audit of buildings_ A review. *Renewable and Sustainable Energy Reviews*. Vol.82, pp3077-3090.

[6] Hoegner, L. and Stilla, U. (2009). Thermal leakage detection on building facades using infrared textures generated by mobile mapping. *Urban Remote Sensing Joint Event*. IEEE, 2009, pp1-6.

[7] Middel, A., Huff, M., Scott Krayenhoff, E., Udupa, A. and Schneider, F.A (2023). PanoMRT: Panoramic infrared thermography to model human thermal exposure and comfort. *Science of the Total Environment*. Vol.859, p160301.

[8] Roupioz L., Kastendeuch P., Nerry F., Colin J., Najjar G. and Luhahe R., (2018). Description and assessment of the building surface temperature modelling in LASER/F. *Energy and Buildings*. Vol.173, pp91-102.

[9] Zhao, Q., Yang, J., Wang, Z.-H. and Wentz, E.A. (2018). Assessing the cooling benefits of tree shade by an outdoor urban physical model at Tempe, AZ. *Urban Sci*. Vol.2, No.1, p4.

[10] Zhao, Q., Wentz, E.A. and Murray, A.T. (2017). Tree shade coverage optimization in an urban residential environment. *Building and Environment*. Vol.115, pp269-280.

[11] Park, Y., Guldmann J-M. and Liu, D. (2021). Impacts of tree and building shades on the urban heat island: Combining remote sensing, 3D digital city and spatial regression approaches. *Computers, Environment and Urban Systems*. Vol.88, p101655.

[12] Macher, H. and Landes, T. (2022). Combining TIR images and point clouds for urban scenes modelling, XXIV ISPRS Congress "Imaging today, foreseeing tomorrow", Commission II 2022 edition, 6–11 June 2022, Nice, France, pp425-431.

[13] Roupioz, L., Nerry, F. and Colin, J. (2018). Correction for the Impact of the Surface Characteristics on the Estimation of the Effective Emissivity at Fine Resolution in Urban Areas. *Remote Sensing*. Vol.10, No.5, p746.

Acknowledgment

The authors would like to thank the Agence Nationale de la Recherche (ANR) for supporting the project TIR4sTREEt (ANR- 21 CE 22 0021). They also thank E. Marie, master student in surveying at INSA Strasbourg for his contribution to this work.