NUMERICAL ANALYSIS OF CRAWL SPACES AIRFLOW

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Abstract

Unlike Central Europe (specifically the Czech Republic), where crawl spaces are not very common, their use is traditional in Nordic countries. However, due to the microclimate within crawl spaces, summertime can be problematic. The relative humidity within a crawl space can reach values of up to 95% [1]. Various factors, including airflow, influence the microclimate of crawl spaces.

This paper focuses on simulating airflow and air age in a naturally ventilated soil space in the Czech Republic using OpenFOAM software. The study involves monitoring internal airflow, surface temperature of the crawl space floor and ceiling structure, as well as air humidity and temperature.

Keywords

Simulation, naturally ventilated crawl space, airflow

1 INTRODUCTION

Crawl spaces are not widespread in Central Europe. In the Czech Republic, it is more common to find timber buildings with strip foundations featuring concrete slab-on-ground. The crawl space is usually ventilated. However, unventilated crawl space constructions can be problematic if measures against ground moisture are not consistently implemented [2]. Crawl spaces can be ventilated mechanically or naturally. Mechanical ventilation options of crawl spaces can be pressurised or depressurised systems. The advantages of mechanical ventilation can be the control over the amount of supply and exhaust air quantities. In a pressurized system, air is blown into the crawl space by a fan, reducing the flow of ground moisture and radon. However, with a pressurized system, the risk of air infiltration from the crawl space into the living space is increased. With a depressurized system, the flow of soil moisture or radon is increased. Along with the infiltrated air, mould spores may enter the living space. Airflow behaviour within a crawl space is also influenced by the wind around the building, which can change the pressure conditions in the structure [3], [4]. The study of Bok at. al. [5] focused on the presence of mould in crawl spaces, identifying species such as *Penicillium corylophilum.* In addition, indoor air contamination from crawl spaces is addressed in the study conducted by Airaksinen et. al [6]. Numerical modelling of air infiltration was the subject of a study conducted by Domhagen et. al. which used statistical Monte Carlo simulation modelling [7].

The aim of this work is to simulate airflow and air age within a crawl space. The simulations were performed in order to align the calculated results as closely as possible with the measured airflow values in the crawl space. For the simulation of air age, the aim was to illustrate how long air can remain in the crawl space under given conditions.

2 METHODOLOGY

The monitored timber detached house in question is located in the South Moravian Region, Czech Republic, at an altitude of approximately 340 m above sea level. The house has a rectangular floor plan. The dimensions of the house are 10.680 × 6.740 m.

The foundations consist of foundation strips, and the enclosing walls of the crawl space are made from concrete blocks – breeze blocks. The bottom of the crawl space is approximately 750 mm below the ground level. Geotextile and aggregate with fraction 16/32 cover the bottom of the crawl space. The height of the crawl space is 1.2 m. The crawl space is naturally ventilated, featuring ventilation holes in the foundation walls. The dimensions of the holes are 250 × 500 mm and are not cover by any grid. The U-value of the ceiling structure of the crawl space is 0.115 W/(m^{2}K). The thermal 360 mm thick insulation is placed in the ceiling structure between Steico beams. The house was built between the years 2013 and 2014. Fig. 1 shows a schema of the monitored crawl space.

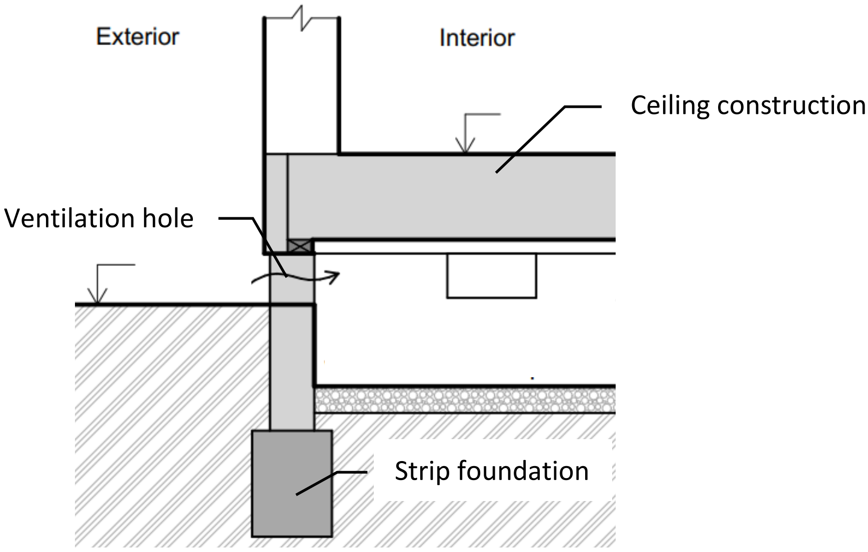

Fig. 1 Schematic of crawl space construction.

Boundary condition and monitoring parameters

The outdoor climatic conditions were monitored at an approximate distance of 700 m in a straight line from the house using Mobile Alerts sensors. In the crawl space, air flow was monitored continuously at 15 min. intervals and an Almemo FVAD 35 hot-wire thermoanemometer was used for temperature measurements. The outdoor air flow was measured on the roof of the house at a height of approximately 4.5 m from the ground using a bowl anemometer. Data collection took place from April 2022 to December 2022.

The median outdoor airflow was selected as the boundary condition for the simulations. The minimum value of the median outdoor airflow i.e. 0.4 m/s (using sensor T17) – autumn 2022 was selected to simulate the external boundary conditions. For the outer boundary condition of the wind flow, the logarithmic wind law was used. In the autumn of 2022, the median airflow within the hole was 0.30 m/s (using sensor T17). The median value was chosen because the airflow measurements contained extreme values. The ground roughness z_0 was estimated based on the location of the house.

The presence of a fence near the house can affect the airflow in the crawl space, therefore the direction of flow rather than the prevailing direction (west) was considered. Tab. 1 shows the median and average values of the measured parameters. It is worth mentioning that there is a significant difference between mean and median values for outdoor airflow.

Tab. 1 Median of measured values and average of measured values.

Sensor	Median of measured values m/s	Average of measured values m/s
T17	0.30	0.38
Exterior	0.40	0.65

Simulation of air flow and simulation of air age

The simulations were performed using OpenFOAM software, where a simplified model of the house was created. Slight irregularities in the surrounding terrain were neglected in the simulation. The roughness of the terrain was taken into account represented by the terrain roughness parameter z_0. Equation (1) shows the roughness coefficient [8].

$$c_r(\mathrm{z}) = k_r \cdot \ln\left(\frac{z}{z_0}\right) \tag{1}$$

where, c_r is the roughness coefficient, k_r is the terrain coefficient, and z_0 is the terrain roughness parameter.

The isothermal stationary model was chosen. The air temperature difference between the crawl space and the outside environment was very low. The convergence limit was 10^{-3}. Airflow and air age were simulated in the naturally ventilated crawl space and two variants were considered. In the first solution, all ventilation holes were open while in the second variant, the ventilation holes were covered to simulate a scenario where these holes would be covered in anticipation of a future house extension. The age of the air in the crawl space was also calculated for both variants.

3 RESULTS

Sensor T17 was located on the west side of the monitored house, while sensor T18 was located on the east side. Fig. 2 shows the air flow through the holes within the crawl space.

Airflow measurements were conducted within the crawl space with all ventilation holes open. The measurement interval was 15 min.

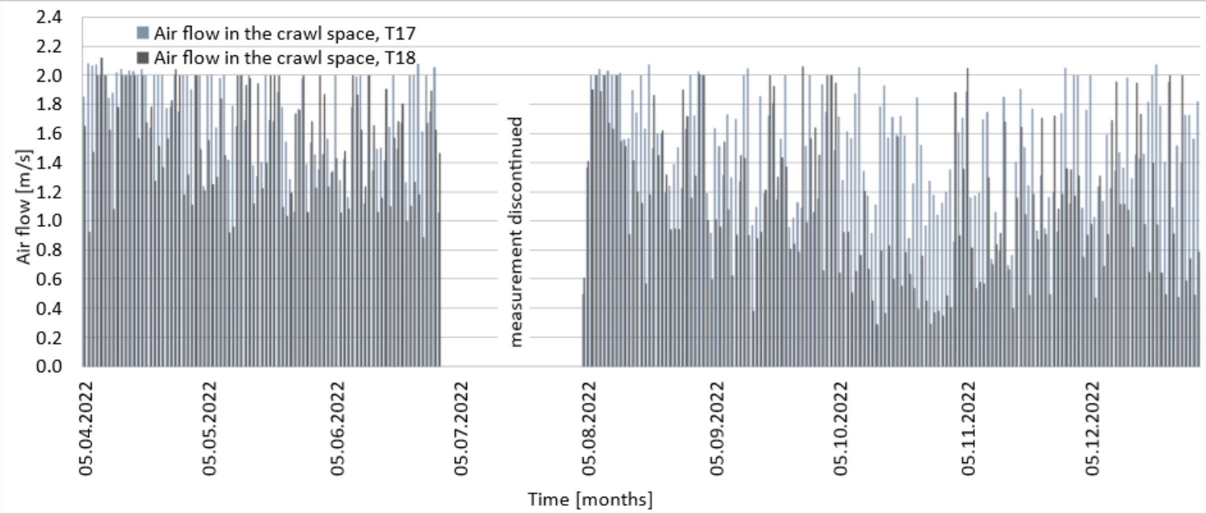

Fig. 2 Air flow in the crawl space, measuring interval 15 minutes.

The fluctuation of outdoor air flow was very high as depicted in Fig. 3. The chart presents the extreme values, with a maximum airflow value reaching 9.5 m/s. The measurement interval for outdoor airflow was 7 min.

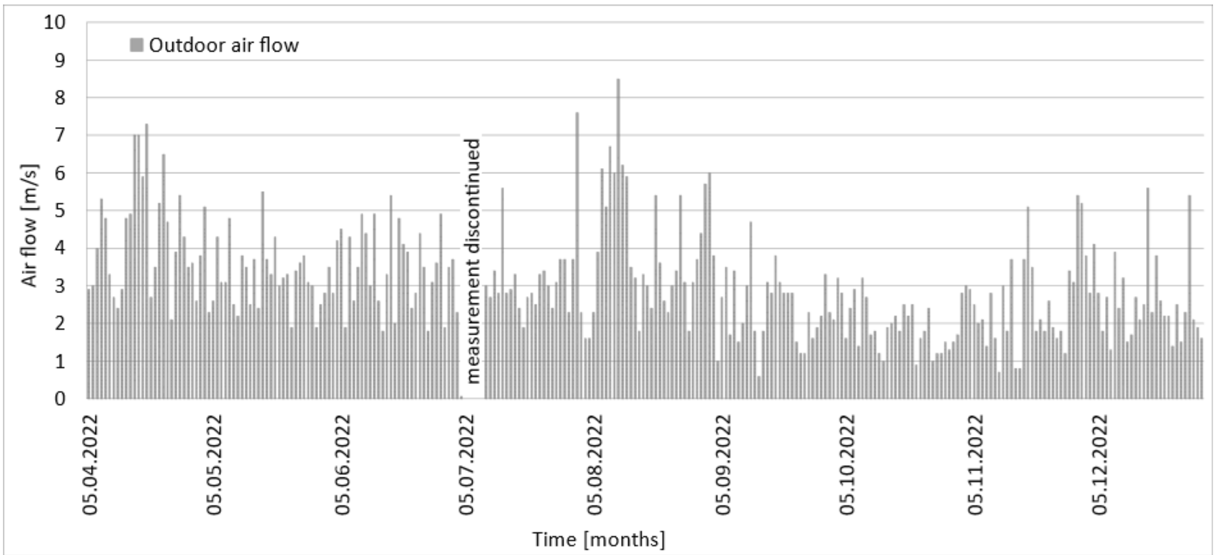

Fig. 3 Outdoor air flow, measuring interval 7 minutes.

DOI 10.13164/juniorstav.2024.24073

Simulation of air flow

In the first version of the simulation, all vents were open. Air flow was allowed through all 15 ventilation openings. The airflow streamlines are shown in the Fig. 4. The outdoor air boundary condition was 0.4 m/s. The simulation achieved a value in the ventilation hole of 0.27 m/s and the median of the measured values was 0.30 m/s.

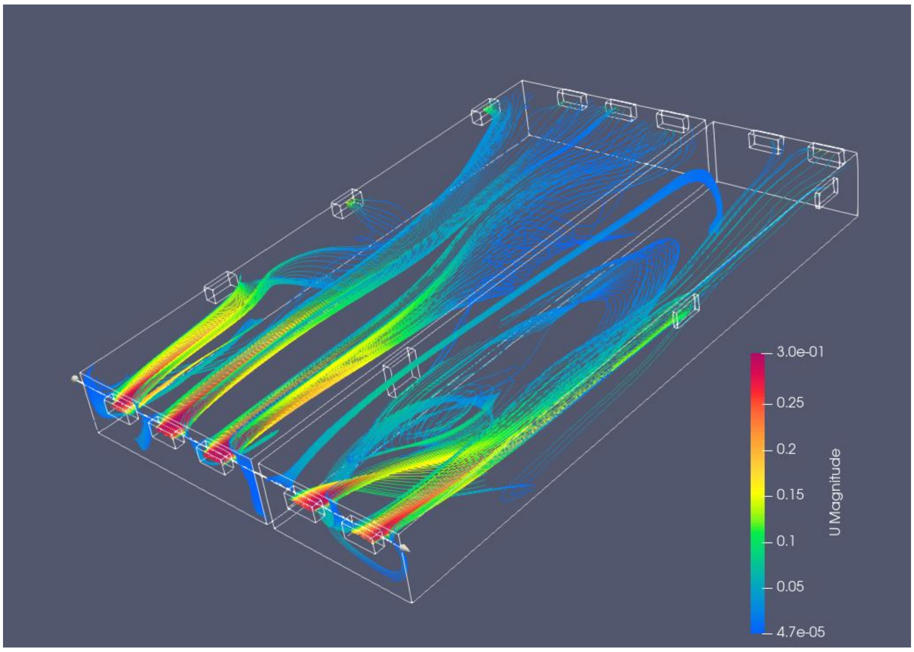

Fig. 4 Airflow simulation in the crawl space – all ventilation holes open, outdoor air flow 0.4 m/s.

In the second version of the simulation, only two vents were open with covered ventilation holes located in the smaller tract on the north side. The airflow streamlines are shown in the Fig. 5 With the ventilation holes closed, the incoming air exits through the opposite ventilation hole. The air is only bypassed at the outer wall and does not enter the space of the smaller tract too much.

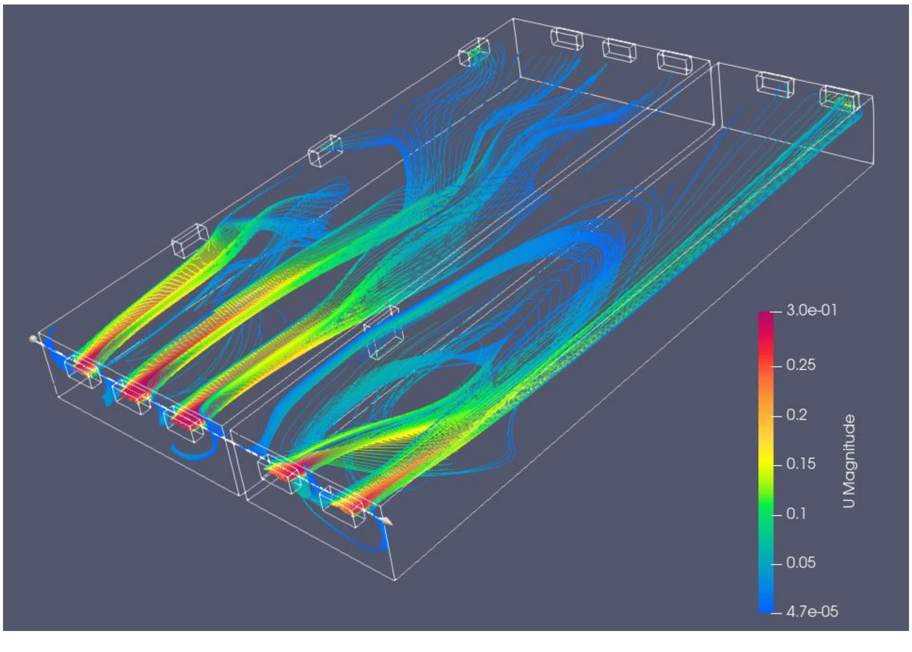

Fig. 5 Airflow simulation in the crawl space – two ventilation holes covered, outdoor air flow 0.4 m/s.

The plot fence was taken into account in the airflow simulation. The fence consists of a gabion wall with wooden infill and the airflow over the fence is restricted. Fig. 6 shows air swirling behind the fence structure.

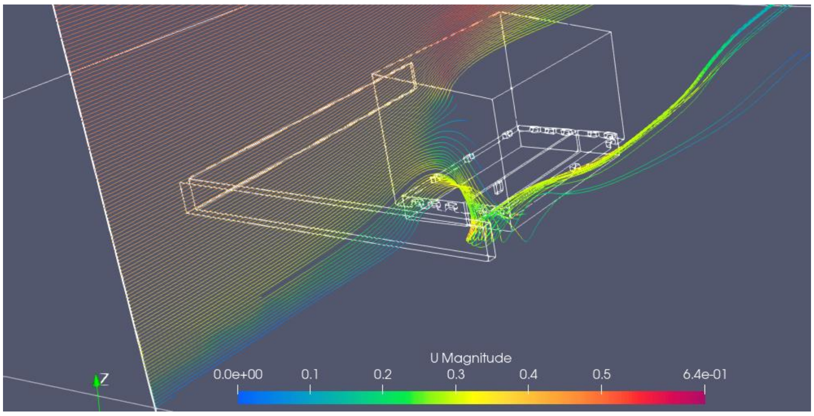

Fig. 6 External aerodynamics of the monitored house outdoor air flow 0.4 m/s.

The actual boundary condition within the crawl space is compared with the simulated values. Tab. 2 summarizes the results of the measurements and simulations in the crawl space. The difference between the calculated value and the measured value was 0.03 m/s.

Tab. 2 Results of the measurement and simulation in the crawl space.

Sensor	**Boundary condition m/s**	**Median of measured values m/s**	**Simulation value m/s**
T17	0.4	0.30	0.27

Simulation of air age

An air age simulation was performed as part of the study. The boundary condition of the outdoor airflow remained the same as that of the airflow simulation, that is 0.4 m/s. Two variants were simulated: one with all ventilation holes open and the other with two ventilation holes covered.

Fig. 7 shows the air distribution within the crawl space with all vents open. The difference between the large tract and the small tract of the crawl space is quite large. The air stayed longer in the smaller tract than in the larger tract. Specifically, at the center wall, air stays for about 13 min in the small tract.

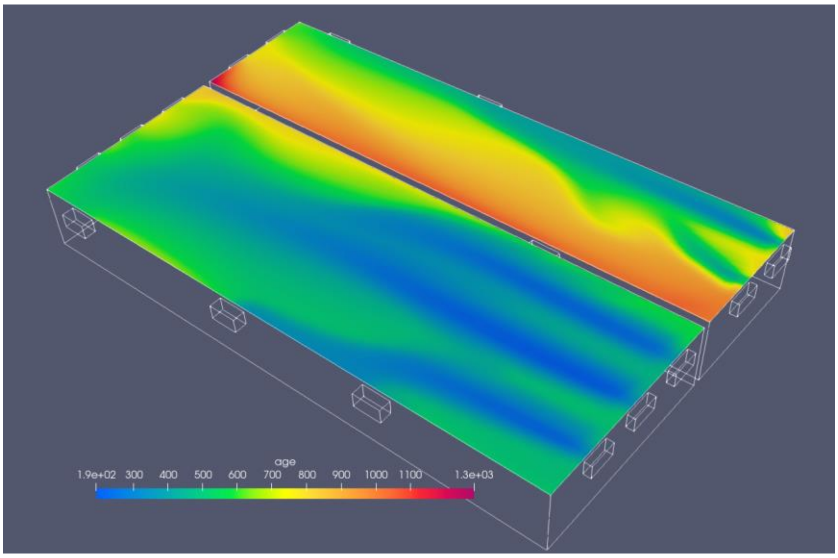

Fig. 7 Age of the air in the crawl space, two ventilation holes covered, outdoor air flow 0.4 m/s.

In the second version of the simulation, only two ventilation holes were open. Comparing the results between the two solution variants, higher values are observed in the crawl space for the second solution variant than for the first. Notably, air retention was prolonged at the centre wall in both the smaller and larger tracts as indicated by the red areas in Fig. 8. The imaginary air particles were observed to remain within the crawl space for up to 15 min.

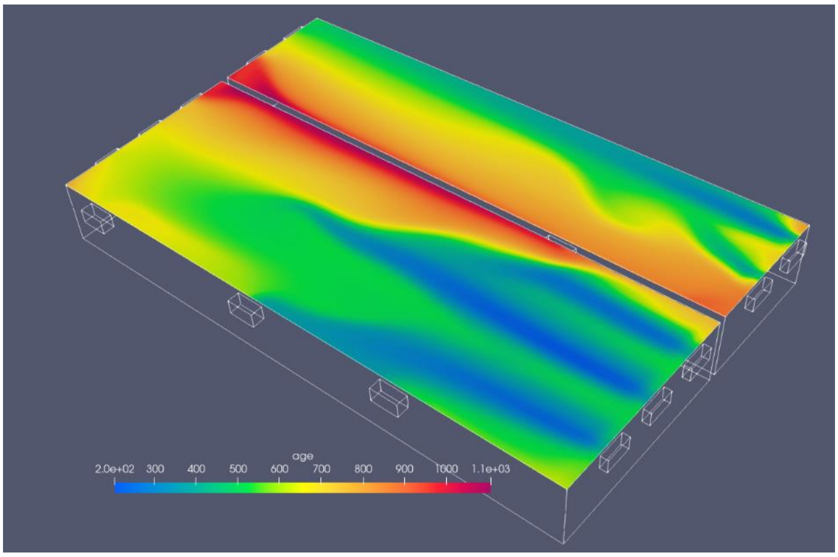

Fig. 8 Age of the air in the crawl space, two ventilation holes covered, outdoor air flow 0.4 m/s.

4 DISCUSSION

In the Czech Republic, the standard value for air exchange rate in crawl spaces has not been precisely defined. The requirements and recommendations for the United States are specified in the International Residential Code [9]. Finland uses the National Recommendation LVI 06-40064 2004) [10] where the recommended air exchange rate is between 0.5 to 1.0 h^{-1}.

Numerous studies have explored simulations in crawl spaces, with a broad focus on various aspects. Using CFD software, the study of Erickson et. al. (2008) [9] evaluated crawl space ventilation requirements according to the International Residential Code (IRC). Using a simulation model, the study conducted by Risberg (2020) [11] determined the heat loss within crawl spaces. The study of Høegh (2017) [12] dealt with the simulation of the effect of a solar power ventilation system.

The outdoor conditions around the building have a significant impact on the microclimate within the crawl space and the related airflow beaviour. Additionally, parameters such as the thermal capacity of the crawl space enclosing structures, and the crawl space bottom or the type of bottom covering significantly shape the behaviour of the microclimate within crawl spaces. The air supplied brings various impurities, such as mould spores, into the crawl space. These can become trapped on the restrictive foundation structures. If conditions are suitable, mould growth can develop on the surface of the structure posing health risks and structural concerns.

This paper focuses on simulating airflow and air age within the crawl space of the detached house. Airflow measurements within the crawl space were conducted with all ventilation holes open. The calculated airflow velocity in the crawl space was then compared with the median measurement obtained from sensor T17. At an outdoor airflow of 0.4 m/s, the calculated value in the ventilation hole was 0.27 m/s, with a deviation from the median measurement of 0.03 m/s. The deviation of the simulation from the measurement could be attributed to: the boundary conditions of the outdoor airflow having been measured approximately 700 m from the monitored house, simplification of the model or the terrain roughness parameter z_0 was estimated based on the terrain category.

Furthermore, the air age simulations revealed that when the two ventilation openings in the small crawl space were covered, the air stayed around the centre wall for up to 15 min.

5 CONCLUSION

This study focuses on simulating airflow and air age within the crawl space of a detached house located in the Czech Republic. The simulations were conducted using OpenFOAM software. The boundary condition for the simulation was determined from the measurements taken, resulting in a deviation of 0.03 m/s between calculated and measured airflow velocities at the openings. Furthermore, the air age simulations revealed that air remained longer in the crawl space when the two vents were closed. Specifically, imaginary air particles were observed to linger most in the corners of the structure.

Acknowledgement

The paper was supported by the Brno University of Technology, Faculty of Civil Engineering – Junior Specific Research No. FAST-J-23-8251 – Foundation of wooden buildings by crawl space system: continuation of microclimate analysis.

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