Possibilities of organizing microclimate systems on the basis of ultrasonic mist generator

Maria Radkevich[1*], *Olga* Ashirova[1], *Kamila* Shipilova[1]

[1]National Research University "Tashkent Institute of Irrigation and Agricultural Mechanisation Engineers", Kori Niyoziy 39, 100000 Tashkent, Uzbekistan

Abstract. The increase in average annual and summer temperatures in cities adversely affects the health of residents. To address the effects of climate change on urban populations, outdoor microclimate systems that spray liquid droplets are utilized. However, these systems have significant drawbacks, including high water usage and limited efficiency in reducing temperatures. In areas facing water scarcity, such as many Asian countries, microclimate systems that utilise ultrasonic mist generators appear to be a more viable option. This article presents a study examining the operation of a physical model of a climate system incorporating ultrasonic mist generators. Experimental data indicate that the cooling effect is evident within the first 2-3 minutes of system operation, with a temperature decrease rate of 0.7 oC/min observed. A mathematical model has been derived that describes the process of temperature reduction in the unit operation zone. The model is based on a hyperbolic function.

1. Introduction

Global climate change is increasingly evident in the daily experiences of people. Hot and dry weather causes heat stress and as Montazeri suggests [1], this will become more frequent and intense, possibly becoming a regularity by 2040. The urban heat island effect exacerbates these problems in densely populated areas. Raised maximum summer temperatures increase mortality rates and negatively impact wellbeing in the population as evidenced by studies such as Gruzdeva, Ebi et al. [2-5]. Garssen identified a strong correlation between the weekly maximum temperature and fatalities during June-September 2003 in the Netherlands [3]. Additionally, Europe experienced over 70 heat-related deaths in the summer of 2006. Numerous studies have indicated a causal relationship between elevated temperatures and augmented mortality rates amidst urban populations. There is a persistent and growing trend of extreme heat waves, concomitant with the aforementioned temperature spikes, which serve to further exacerbate the deleterious effects on health [4-6].

The urban heat island (UHI) is an inherent feature of contemporary megacities, bringing about a higher air temperature compared to rural regions. Sometimes, urban areas experience localised heat islands where temperatures are higher than their surrounding areas [7].

A "heat island" in a large city typically has an average air temperature 4°C higher than that of its neighbouring regions. However, during the night, with a gentle breeze, the temperature difference can exceed 6-8°C [7].

Thermal emissions from industrial enterprises, transportation and other economic activities, as well as the local "greenhouse effect," contribute to increased temperatures within urban areas. As a result, urban air temperature is commonly 7-15 °C higher than natural environments. Heat accumulators in urban areas such as stone buildings, asphalt and other artificial pavements, further exacerbate this issue. For example, pavement temperatures can reach 52 °C in Moscow, 65-70 °C in Yerevan, 73 °C in Odessa, and 80 °C in Tashkent [7, 8].

It is worth noting that UHIs gather together gaseous and dust emissions that can be detrimental to both humans and the environment, originating from industries, energy production and transportation. These emissions tend to fall on areas of the city that are some distance away from the UHI (in the direction of the prevailing wind) and can be carried by rainfall. These emissions have adverse public health effects.

Moreover, urban heat islands in summer increase energy demand. For nations (such as Uzbekistan) where the majority of electricity derives from burning fossils, it results in augmented air contamination due to the discharge of

*Corresponding author: m.radkevich@tiiame.uz

sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), mercury (Hg), and greenhouse gases [9]. Consequently, all of these cause highly detrimental impacts on the well-being of the inhabitants.

It is essential to develop technical solutions for creating localized climatic comfort zones to maintain the working capacity and everyday life activities of citizens. For hot climate settlements, creating said zones can be a fundamental step towards adapting to climate change. A study [10] emphasises the necessity of developing effective adaptation measures for achieving physiologically comfortable environmental conditions to reduce morbidity and mortality.

A review of existing research and recommendations to reduce the urban heat island effect have identified essential measures:

1) Urban greening can reduce energy consumption for cooling buildings, improve stormwater management, and enhance human comfort by mitigating air pollution [11, 12]. Additionally, it can foster aesthetic and social benefits.

2) "Green roofs" formation enables the cooling of ambient air by evaporation, minimizes the heat gain in the building, diminishes heat transfer to the air above the roof, and results in an overall decline in urban air temperature [12]. A green roof can be up to 40°C cooler than a conventional roof.

3) Cold roofs and pavements reflect more sunlight and heat than they absorb. The use of particular materials can result in surface temperatures up to 28-33°C cooler in the summertime when compared to traditional roofing materials [12]. The temperature could potentially reduce by up to 17-18°C if cold pavements are utilised instead of the traditional ones.

4) A method for artificially ventilating urban streets involves constructing special exhaust devices to generate convective airflows [13]. This technique does not offer significant temperature reduction, but it effectively eliminates harmful gases from human breathing areas.

5) The cooling impact of artificial precipitation is based on the evaporation of moisture [1, 14-17]. Moisture atomization is typically employed to construct small microclimate systems.

Evaporative cooling systems have been employed effectively in urban areas to create comfortable climate conditions. Such systems are commonly used as a strategy to adapt to climate change. The systems entail the use of a jet of air directed at a specific location, while spraying water simultaneously. According to Givoni, directing the airflow onto wetted pavements in front of the building entrance is an effective method [18].

Typically, this technique decreases the air temperature and raises the absolute humidity. Humidified fans [19] and evaporative towers [15] are among the systems that can be integrated into buildings to provide cooling. Technical terms are explained upon first use, and the language is clear, concise, and objective. The text is also free of grammatical errors and follows British English conventions. Additionally, larger-scale cooling systems for buildings and streets can be achieved using water ponds with waterfalls and fountains, as well as wetting pavements and spray systems [14, 17, 20].

In a spray system, water is atomised as a cloud of small droplets via a nozzle or injector, enabling good mixing and enhanced contact between the air and the droplets. In a spray system, water is atomised as a cloud of small droplets via a nozzle or injector, enabling good mixing and enhanced contact between the air and the droplets. This results in high rates of evaporation, leading to more effective cooling of the air.

The application of spray systems for evaporative cooling is on the rise due to their ability to achieve quick cooling and enhance thermal comfort in indoor and outdoor settings [16, 20].

Spray systems offer several benefits over techniques for enhancing thermal comfort, like using envelopes with high surface reflectivity, covering roofs with vegetation, and increasing the heat transfer resistance of structures. Water spraying is a cost-effective and eco-friendly way to enhance the quality of indoor and outdoor environments. It utilizes passive cooling with straightforward components [15].

Atomization systems can be easily integrated into current urban infrastructures and buildings, making the control of their operation performable and responsive to actual needs. These systems are distinguishable from stationary ones which remain active year-round, leading to boosted winter-time energy consumption in some cases [21].

Practical cases of atomisation implementation for climate change adaptation are noticeable in Rotterdam, the Netherlands and further urban areas. The water spray system was positioned within a courtyard that experiences regular high air and surface temperatures. A spray nozzle was installed at a 3-metre height, with a total flow rate of 9 litres per minute and a water temperature of 25°C in the system. Droplets ranging from 10 to 60 µm in diameter were produced by employing a Rosin-Rammler distributor, according to Montazeri et al. [1].

While spraying systems have shown successful results, it is important to consider some of their drawbacks:

- the downward direction of the air-drop flow may cause some unevaporated droplets to deposit on surfaces, potentially resulting in corrosion or damage to the structure's appearance. Additionally, these droplets can be a source of discomfort for individuals if they touch their skin or clothes.
- any breakage or malfunction in the pipework (hoses) can cause the entire system to shut down, necessitating repair.

- the spraying nozzles are susceptible to erosion and blockage and, therefore, need frequent replacement.
- the system itself is stationary and cannot be repositioned.

These drawbacks can be overcome by replacing atomisation systems with ultrasonic cold mist generators. Such devices are commonly implemented for humidifying the air in dwellings, greenhouses and mushroom farms. The fog generator transforms liquid (water) into small particles and atomises them into the air without heating elements, ensuring that the atomised liquid is the same temperature as the surrounding environment. According to Malgin, ultrasonic fog generators possess a relatively simple design, ensuring high efficiency with minimal energy consumption [22]. Additionally, these generators are safe for operation. Unlike conventional atomisation systems, the size of atomised droplets ranges from 0.02 to 15-20 µm. It is noteworthy that these devices provide effective cooling and dust suppression besides air humidification as their primary function, without any droplets falling.

The design is modular, enabling rapid replacement of damaged components and uninterrupted operation. There are no nozzles or pipework, which enhances design reliability and device mobility (i.e. it can be easily relocated).

While the use of cold fog generators for indoor air cooling has been investigated in [23-25], the possibilities of ultrasonic fog generators have been relatively underexplored [26]. The potential applications of ultrasonic fog generators for street microclimates have not yet been researched.

Hence, this article aims to investigate the options for utilizing cold fog generators to establish regions of local climatic comfort within the hot climate of the Republic of Uzbekistan.

2. Materials and Methods

2.1. Research Location

The study was conducted in Tashkent, the capital of Uzbekistan. In recent years, warming in Uzbekistan has surpassed global average rates. Specifically, the average annual temperature increases in Tashkent compared to the 1930s is 2.4 °C, as reported by Uzhydromet. Meanwhile, in Andijan, for instance, this figure is 1.8 °C. The geographical location of Andijan being south of Tashkent cannot account for the difference in temperature increase. The only plausible explanation is that Tashkent is a significant urban area where an urban heat island effect is occurring.

An analysis of weather station readings from 2021 to 2022 in Tashkent revealed that the daytime air temperature in May frequently exceeded 30 °C, which is beyond the bounds of climatic comfort. During summer, air temperatures can reach hazardous levels of 43-44.5 °C, while the average daytime air humidity drops to 30%. Although low air humidity enables a person to better tolerate higher temperatures, relative humidity levels below 40% can be detrimental as they increase moisture loss from the organism, leading to dehydration.

For the experiments, National Research University "Tashkent Institute of Irrigation and Agricultural Mechanisation Engineers" (NRU TIIAME) was selected as the location due to its numerous open areas with asphalt pavement, which are subjected to high temperatures during the summer period.

2.2. Equipment

To evaluate the potential of the proposed technical solutions, an experimental setup was established to represent a physical model of a local climate-controlled zone. A summer canteen situated within the NRU TIIAME premises was selected for modelling, as it experiences critical temperatures above +40 °C despite having a roof in the hot season.

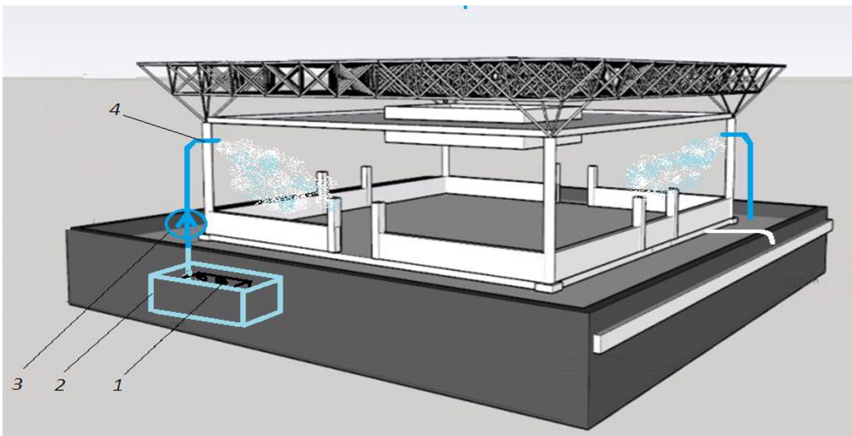

Fig. 1. Working drawings of the model: 1 - 10 Head Ultrasonic Fogger maker; 2 - water tank; 3 - pump; 4 - nozzle for spraying cold fog

Scale of the model depicted in Fig. 1 was set at 1:20, while the calculation of its parameters was based on geometric similarity theory for ensuring the physical quantity similarity at similar points and moments between the model and the original.
Having conducted real-life testing of the model, we believe that the initial conditions (with identical fields of all physical quantities at the initial point in time) and the boundary conditions (with constant ratios of corresponding quantities at the boundaries of both the model and the original) are successfully fulfilled.
Further details regarding the model's architecture can be observed in Fig.1, whilst photographs of the model in operation are displayed in Fig. 2.

Fig. 2. Model of the experimental plot at the beginning of the microclimate formation process

To create microclimate in this model 2 ultrasonic fogger makers with 10 heads were used (Table 1).

Table 1. Technical characteristics of 10 Head Ultrasonic Fogger maker DC48V

Characteristic	Value
Number of working cores	10
Ceramic core diameter	16 mm
Input voltage	DC48V
Input power	20 W
Resonance frequency	1650 50kHz
Maximum atomization amount	2.5 l h^{-1}
Working water temperature	1-55 ^oC
Working water level	60-80 mm

Temperature was monitored using a TPM-10-T digital mini-thermometer with a resolution of 0.1 °C.

2.3. Methodology of the experiment

The experiments were conducted on the territory of NRU TIIAME in August, in the daytime. The duration of one experiment was 30 min, temperature was recorded at 1 min intervals.
The results of the experiment were processed using the Origin 6.0 software package.

3. Results and Discussion

Table 2 presents the findings of temperature measurements from a single experiment.
The average values were computed and depicted in Figure 3, which illustrates the temperature change over a period of 30 minutes.
Using Origin 6.0 software, the obtained graph was approximated using hyperbolic function:

$$y = a - \frac{b}{(1 + cx)^{1/d}} \tag{1}$$

Table 2 shows that the proposed microclimate system reduces the temperature of the model plant by 2.3 to 2.8 ^oC. The smallest temperature drop is observed when the initial air temperature is also minimal (29.6 ^oC). By the end of

the measurements, the average temperature reached 27-28 ºC, which is considered acceptable for indoor microclimate in hot periods according to the norms.
The temperature drop is illustrated in Figure 3, displaying the accompanying diagram and mathematical representation.

Table 2. Experimental values of temperature change in the local climatic comfort zone model

No	Temperature values, °C			
	1st	2nd	3rd	Average
0	30.1	29.6	31.2	30.30
1	28.5	28.9	30.6	29.33
2	28.2	28.5	29.9	28.87
3	28.1	28.3	29.6	28.67
4	28.0	28.2	29.3	28.50
5	27.9	28.1	29.2	28.40
6	27.9	28.0	29.1	28.33
7	27.8	27.9	29.1	28.27
8	27.8	27.9	29.1	28.27
9	27.8	27.9	29.1	28.27
10	27.8	27.8	29.0	28.20
11	27.7	27.8	29.0	28.17
12	27.7	27.7	28.9	28.10
13	27.7	27.7	28.9	28.10
14	27.7	27.7	28.9	28.10
15	27.6	27.7	28.8	28.03
16	27.6	27.6	28.8	28.00
17	27.6	27.6	28.7	27.97
18	27.6	27.6	28.7	27.97
19	27.5	27.5	28.7	27.90
20	27.5	27.5	28.6	27.87
21	27.5	27.5	28.6	27.87
22	27.4	27.5	28.6	27.83
23	27.4	27.4	28.6	27.80
24	27.4	27.4	28.5	27.77
25	27.4	27.3	28.5	27.73
26	27.4	27.3	28.5	27.73
27	27.3	27.3	28.4	27.67
28	27.3	27.3	28.4	27.67
29	27.3	27.3	28.4	27.67
30	27.3	27.3	28.4	27.67
ΔT, ºC	2.8	2.3	2.8	2.63

Figure 3 displays the graph with experimentally obtained points in black, and the approximating curve in red. It is important to note that various attempts were made to approximate the experimental curve with different mathematical functions. However, the hyperbolic function equation (1) achieved the greatest convergence between the experimental data and the model.

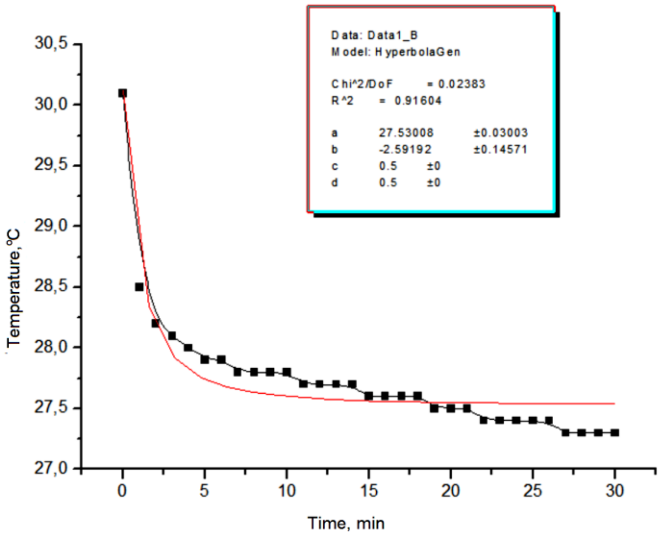

Fig. 3. Graph of temperature decrease in the model of the climatic comfort zone

An equation for the temperature decreases in the analyzed zone is derived from the study.

$$T = 27{,}53008 - \frac{-2.59192}{(1+0.5t)^{1/0.5}} \tag{2}$$

Where *T* is the air temperature in the zone of microclimate creation, °C;
t - time elapsed since the start of the installation, minutes.

Calculated parameters and error values can be found in Table 3.

Table 3. Calculation parameters and accuracy estimates of the model (3)

Parameter	Value	Error
A	27.53008	0.03003
B	-2.59192	0.14571
C	0.5	0
D	0.5	0
Chi^2/DoF		R^2
0.02383		0.91604

Table 3 demonstrates that the error values for the parameters of the mathematical model (2) are minimal, indicating a strong similarity between the experimental and theoretical values. The high correspondence of the model to the experimental data is further supported by the coefficient of determination value of R^2=0.91604. It is widely accepted that the closer the coefficient value is to 1, the stronger the dependence. Consequently, the model obtained can be used for estimating and forecasting calculations when designing microclimate plants.
As evident from the collected data, the cooling effect of the suggested climatic unit is inconsistent within its operating zone. Therefore, the primary cooling potential of the unit can be observed within the initial 2-3 minutes, which can be a testimony of its reasonable competency. The temperature plunges by an average of 1.4 °C in the maiden two minutes with a rate of 0.7 °C/minute = 0.01 °C/second, then the rate slows down to 0.043 °C/minute = 0.000714 °C/second. This is also in line with findings from previous research on the efficacy of ultrasonic fogging devices for cooling indoor spaces [26].

4. Conclusions

The study findings indicate that ultrasonic fog generators are a viable option for cooling open spaces. By implementing these generators, it is possible to establish zones that provide local climate comfort and effectively mitigate dust and gas. Using this approach, it is feasible to adapt to climate change and reduce the impact of urban heat islands.
Considering the proposed plant design's low cost and low energy and water consumption, it can be inferred that in countries facing water and energy scarcity, such as Uzbekistan, these plants are more appropriate than evaporator plants utilizing pressurized water spraying.
The subsequent step is to examine the large-size plant's operating modes in actual conditions, to appraise the liquid evaporation rate and the level of influence on urban heat island formation.

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