



Article

Influence of Microclimate on Favourable Working Conditions of Agricultural Workers on the Harvesting Platform

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Abstract

This manuscript investigates the influence of microclimatic factors on favourable working conditions for agricultural workers, with an emphasis on air temperature, humidity, and air velocity inside greenhouses at their workplaces. Analysis of the results of air temperature, humidity, and air velocity revealed that the internal conditions inside the greenhouse change throughout the day, which may have an impact on the thermal comfort of workers and their work efficiency. Also, analysis of air velocity indicates the need to optimise ventilation systems to improve working conditions. The data obtained through statistical processing can serve as a basis for further research and development of systems that would ensure more stable and favourable microclimatic conditions in protected areas of agricultural production.

Keywords: agricultural worker; harvesting platform; microclimate; working condition

1. Introduction

Ergonomics is a scientific discipline concerned with the interaction between the workplace, the worker, and the environment. Since workers in greenhouses are exposed to more demanding working conditions, particular emphasis is placed on microclimatic factors and their effects. The primary microclimatic parameters investigated include air temperature, relative humidity, and air velocity. These factors may adversely affect the health of workers operating on harvesting platforms in protected environments, as well as their work performance and productivity [1].

Thermal comfort is a complex concept, which can vary greatly from one individual to another. It is defined as the feeling of well-being that people experience in a given space according to ISO 7730 [2]. It is determined by the combined influence of environmental factors (air temperature, mean radiant temperature, air velocity, and relative humidity) together with personal factors such as metabolic rate and clothing insulation. In occupational settings, particularly in greenhouse production, maintaining thermal comfort is essential not only for workers' health and safety but also for productivity, cognitive performance, and overall well-being. Greenhouses are characterised by pronounced spatial and temporal variability of microclimatic conditions caused by solar radiation, limited air exchange, and plant transpiration, making the assessment of thermal stress particularly challenging. Several thermal comfort indices have been developed to quantify human thermal perception and heat strain under different environmental conditions. Among the most widely used are the Predicted Mean Vote (PMV), the Wet Bulb Globe Temperature (WBGT), and the Universal Thermal Climate Index (UTCI).



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The Predicted Mean Vote (PMV) model, developed by Fanger (1970) [3], predicts the average thermal sensation vote of a large group of people on a seven-point scale ranging from cold (−3) to hot (+3) (Fanger, 1970) [3]. PMV is based on the human heat balance equation and incorporates six variables: air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate, and clothing insulation. Although PMV remains the reference model in indoor environmental standards such as ISO 7730 [2] and American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 55, it assumes steady-state conditions and was primarily developed for climate-controlled indoor environments. Consequently, its applicability to naturally ventilated greenhouses is limited because workers are exposed to rapidly changing environmental conditions and variable physical workloads (Parsons, 2014) [4]. The Wet Bulb Globe Temperature (WBGT) index is one of the most commonly used methods for occupational heat stress assessment. Introduced by Yaglou and Minard (1957) [5], WBGT combines natural wet-bulb temperature, globe temperature, and dry-bulb air temperature into a single indicator representing the combined effects of air temperature, humidity, radiant heat, and air movement. Due to its simplicity and strong association with physiological heat strain, WBGT has been adopted by ISO 7243 [6] and numerous occupational health organisations worldwide. Nevertheless, WBGT does not explicitly account for clothing insulation, metabolic rate, or adaptive human responses, which may reduce its sensitivity when evaluating complex working environments such as greenhouses. The Universal Thermal Climate Index (UTCI) represents a more advanced approach to thermal stress assessment. Developed through international collaboration coordinated by the European COST Action 730, UTCI is based on a sophisticated multi-node thermophysiological model coupled with a dynamic clothing model (Jendritzky et al., 2012 [7]; Bröde et al., 2012 [8]). Unlike PMV and WBGT, UTCI integrates air temperature, mean radiant temperature, wind speed, and humidity while simultaneously accounting for human thermoregulation under transient environmental conditions. Consequently, UTCI has become increasingly recognised as one of the most comprehensive indices for evaluating outdoor and semi-enclosed thermal environments and has been successfully applied in occupational health, urban climatology, and agricultural research.

The aim of this study is to determine the influence of microclimatic factors (air temperature, relative humidity and air velocity) on the working conditions of workers operating on harvesting platforms. The research hypothesis assumes that, during the working day, air temperature will increase, while relative humidity and air velocity will decrease.

Climate change is increasingly evident and has been addressed by numerous authors from different perspectives. Marchetti et al. [9] conducted a study aimed at assessing the impact of microclimate on workers, particularly in terms of health and productivity. Their review indicated that, over the past three decades, an increase in average air temperature and the frequency of heat-related events, combined with other factors (e.g., individual susceptibility and work-related conditions), has led to an increased severity of health risks, including heat stress and mortality. The most vulnerable workers are those employed outdoors in tropical and subtropical regions, exposed to excessive heat and engaged in physically demanding tasks. However, it is important to emphasise that negative effects are also observed among non-cooled indoor workers, such as those in greenhouses.

Numerous studies highlight the issue of reduced work capacity and productivity when workers are exposed to prolonged heat stress, particularly during physically demanding activities. These adverse effects are reflected in decreased cognitive performance (e.g., alertness) and prolonged reaction times, ultimately compromising occupational safety, especially in high-risk tasks (e.g., operators and night-shift workers in production). Therefore, the implementation of preventive measures based on a multidisciplinary approach

and effective control strategies is of paramount importance in order to mitigate health risks and improve work performance.

Ferrante et al. [10] investigated the impact of microclimate on workers across 38 operating rooms and reported that microclimatic parameters exceeded permissible limits, which was associated with reduced work performance. Kralikova and Wessely [11] examined the influence of environmental factors, including illuminance (lx), air temperature (°C), relative humidity (%), and air velocity (m/s), on operator productivity in mechanical engineering assembly processes. All parameters were measured using a calibrated multifunctional device, followed by a survey and statistical analysis to identify the most significant factors affecting productivity. The results indicated that increased illuminance and air temperature were associated with higher worker productivity.

Kralikova and Koblasa [12] analysed the impact of microclimatic conditions in mechanical workshops from the perspective of worker comfort. By measuring air temperature, relative humidity, and air velocity, they demonstrated that these parameters significantly influence perceived comfort. Kotek et al. [13] investigated the effects of microclimate on workers in the chemical, energy, and gas industries and identified discrepancies between actual environmental conditions and recommended standards (air temperature, humidity, and CO₂ levels). They emphasised that appropriate selection of microclimate control systems is essential to regulate air temperature, while ventilation should be adjusted according to indoor moisture sources and external humidity conditions. Additionally, the use of CO₂-controlled ventilation systems can improve indoor air quality.

Toşu et al. [14] reported that microclimatic conditions in industrial environments directly affect worker efficiency and the quality of performed tasks. Their study analysed the relationship between microclimate parameters (air temperature, relative humidity, air velocity and illuminance) and operational performance in a mechanical workshop. Based on simulated data obtained through numerical modelling and controlled observations, the authors identified a significant correlation between increased air temperature and decreased worker efficiency, particularly in tasks involving moderate physical effort. The study further suggests that simulation models can serve as valuable tools for ergonomists and occupational health and safety professionals in optimising microclimate conditions in industrial settings. Wróblewski et al. [15] investigated air temperature in relation to its impact on a worker operating a rock-breaking machine in an underground mining cabin. The measured ambient air temperature reached 38 °C. Subsequently, the authors developed a cabin simulation model and proposed guidelines to improve operator protection. The simulation results indicated that reducing the air temperature by 8 °C, combined with increasing air velocity to 4 m/s, could significantly mitigate adverse health effects for the operator.

Zewdie and Kic [16] analysed microclimatic conditions at the operator position in three different combine harvester models. Their findings showed that, in one model (E 517), the air temperature exceeded the limit (39.1 °C), while relative humidity was below the recommended level (28.3%). The authors emphasised that future research should focus more extensively on the effects of microclimate on operators and workers, as this aspect remains insufficiently addressed despite its significant impact on both health and productivity.

Graham et al. [17] examined microclimate from the perspective of architectural design. In the context of ongoing climate change, it is increasingly important for architects to understand the effects of design interventions on both indoor and outdoor thermal comfort. Emerging microclimate analysis tools are gaining importance, enabling the evaluation of design alternatives based on biometeorological indicators such as the Universal Thermal Climate Index (UTCI) and Outdoor Thermal Comfort Autonomy (OTCA). Their study

demonstrated that existing toolsets, particularly ENVI-met, require substantial adaptation for such applications. The authors proposed several extensions and open-source solutions to facilitate this process, with key advantages including improved software interoperability, accelerated simulation development and analysis, and the ability to calculate emerging thermal comfort metrics. However, further advancements are required before microclimate can be fully integrated as a primary driver in architectural design.

Ogunlowo et al. [18] conducted a study investigating heat and mass distribution at sensor nodes within greenhouse systems. Three types of greenhouses were analysed: a single-layer greenhouse (SLG), a double-layer greenhouse (DLG), both with a Gothic roof and a surface area of 168 m², and a multi-span greenhouse (MSG) with an area of 7572.6 m². The investigated microclimatic parameters included air temperature (T), relative humidity (RH), solar radiation (SR), carbon dioxide concentration (CO₂), and vapour pressure deficit (VPD). To determine horizontal distribution patterns, microclimate data were collected from each sensor node in all greenhouses and analysed using descriptive statistics and Tukey's honestly significant difference (HSD) test. The lowest minimum air temperatures recorded were 2.93 °C, 3.33 °C and 10.50 °C in the SLG, DLG and MSG, respectively, while the highest maximum air temperatures were 29.17 °C, 29.07 °C and 27.20 °C in the same systems. The temperature difference between the central and lateral zones within a single span ranged from approximately 0.88 to 1.0 °C and about 1.03 °C in the MSG. Significant spatial variability was observed in the horizontal distribution of T, RH, SR, and VPD across all greenhouse types. Chen et al. [19] emphasised that agriculture is highly sensitive to climate change, with greenhouse cultivation identified as a potential mitigation strategy. However, short-term prediction of microclimate conditions remains challenging due to the strong interdependence and rapid variability of meteorological variables, which directly affects workers in protected environments. To address this issue, the authors proposed a smart microclimate control system (SMCS) focused on water management, integrating system dynamics and machine learning techniques. The system considers internal hydrometeorological processes to regulate the greenhouse microenvironment at canopy level, aiming to enhance cooling efficiency and resource utilisation. The SMCS was evaluated using in situ data collected from a tomato greenhouse in Taiwan. The results indicated that the proposed system could reduce water and energy consumption by up to 66.8% for early-stage spraying throughout the growing period compared to conventional greenhouse spraying systems, which are largely based on operator experience. The proposed SMCS represents a practical advancement in greenhouse automation, enabling improved crop productivity, enhanced resource efficiency and better protection of workers.

According to the provisions of the Ordinance on the Testing of the Working Environment, employers are required to ensure, in a prescribed manner, the assessment of workplace environmental conditions in the following cases: (1) when the work process affects air temperature, relative humidity and air velocity; (2) when it is necessary to ensure an adequate level of illuminance; (3) when noise or vibration is generated during work processes; (4) when gases, vapours, dust, or aerosols are produced; and (5) when there is a potential presence of biological hazards (agents) used outside primary physical containment (OF, 16/2016 [20]).

In indoor workplaces, favourable working conditions must be ensured depending on the nature of the work, particularly with respect to air temperature, relative humidity and air velocity, while considering work processes and the physical demands placed on workers. Where permitted by the work process, the following microclimatic conditions should be ensured during the cold (winter) period: 20–25 °C for sedentary work, 16–22 °C for light physical work and 10–19 °C for heavy physical work. When air-conditioning systems are used, they must be adapted to the type of work and technological processes in accordance

with applicable technical regulations. A relative humidity range of 40–60% is recommended under air-conditioned conditions. During the warm (summer) period, the difference between outdoor and indoor air temperature should generally not exceed 7 °C. Air velocity at indoor workplaces depends on the type of work and technological process and should not exceed 0.5 m/s when the outdoor temperature is up to 10 °C, 0.6 m/s when the outdoor temperature ranges from 10 °C to 27 °C, and 0.8 m/s when the outdoor temperature exceeds 27 °C. Air temperature in rest areas, staff rooms, sanitary facilities, dining areas, and first aid rooms must be appropriate to their intended use. Windows, skylights, and glass partitions must prevent excessive solar radiation exposure at workplaces, taking into account the nature of the work and energy efficiency. Regarding protection against adverse thermal conditions (work at low and high air temperatures), employers are required to comply with the recommendations and guidelines issued by the competent public health authority in the field of occupational medicine (OG, 105/2020 [21]). The classification of greenhouse work was determined through occupational risk assessment based on measurements of the microclimatic conditions and evaluation of workers' physical workload. Physical workload was assessed by observing work-related activities, including manual handling of loads (e.g., carrying tomato crates) and the adoption of awkward postures, such as working in a bent or squatting position for at least 50% of the working time. Owing to the elevated ambient temperatures characteristic of greenhouse environments, together with the substantial physical demands associated with tomato harvesting and the manual transport of tomato crates, greenhouse work was classified as heavy physical work during the study period [22].

During the work process, agricultural workers are exposed to a wide range of hazardous and harmful working conditions that may, under certain circumstances, lead to adverse health effects. These conditions include hazards, harmful exposures, and physical strain, and may be mechanical, chemical, physical, biological, ergonomic, or psychological in nature. Hazards primarily result in occupational injuries, whereas harmful exposures and physical strain are most commonly associated with occupational diseases and work-related illnesses. The most frequent hazards in agriculture include mechanical risks associated with the use of machinery, equipment, and tools, as well as falls on the same level, into depths, or from heights; electrical hazards arising from the use and maintenance of electrical equipment and installations; fire and explosion hazards related to flammable and explosive substances (e.g., fuels and pesticides); and risks associated with working with animals, including bites, punctures, or crushing injuries [23]. Agriculture and forestry are among the most hazardous professions in Europe, characterised by a high incidence of accidents that affect the sustainability of the sector. Over the past decade, the sector has recorded, on average, more than 500 fatal accidents annually and over 150,000 non-fatal accidents. Recent studies indicate a significant underreporting of both fatal and non-fatal accidents across Europe. In many cases, national statistics place agriculture and forestry among the highest-risk sectors in terms of occupational hazards [24]. Workers exposed to high air temperatures are at risk of dizziness, fainting, and heat cramps. Under extreme conditions, body core temperature may increase; if it exceeds 39 °C, there is a risk of heat stroke or collapse. Increasing evidence suggests that occupational heat stress is associated with kidney disease among outdoor workers. Even at moderately elevated temperatures, heat can lead to reduced concentration and increased fatigue, thereby increasing the likelihood of accidents. High temperatures contribute to decreased cognitive performance, slippery hands due to sweating, and discomfort associated with personal protective equipment, which may result in its improper use or non-use. Heat can also exacerbate pre-existing medical conditions, such as hypertension and cardiovascular diseases, due to increased cardiac strain, as well as through interactions with other workplace hazards. Pregnant workers are particularly vulnerable to high temperatures, and specific protective measures

are required to ensure their safety. Optimal work performance is generally achieved at air temperatures between 16 °C and 24 °C, although this range may vary depending on the type of work performed (ETUC, 2018 [25]). Thermal comfort is also influenced by evaporative cooling processes; therefore, relative humidity plays an important role. A relative humidity range of 35–60% is recommended at air temperatures between 20 and 22 °C. When relative humidity falls below 35%, which may occur during winter in heated indoor environments, increased dust formation can occur due to drying of materials such as textiles and furniture. The combustion of such dust on heating surfaces may release ammonia and other irritant gases. Additionally, synthetic materials tend to accumulate electrostatic charge in dry air, attracting dust particles. Low humidity can also lead to drying of the mucous membranes of the upper respiratory tract, impairing their protective function and increasing susceptibility to infections such as colds and influenza, as viruses tend to survive longer in dry and cold conditions. Very dry air may also negatively affect the skin, causing irritation and eczema. For this reason, maintaining a minimum indoor humidity level of 35% during winter is recommended.

At relative humidity levels above 60%, conditions become favourable for surface condensation and the development of fungi and mould. At 60% humidity, sweating begins at approximately 25 °C, whereas at 50% humidity, it begins at around 28 °C. Under normal indoor conditions (20–22 °C), relative humidity should be maintained between 35% and 60%, while at higher air temperatures (>26 °C), humidity levels should be reduced. In indoor environments, humans are sensitive to air movement; the most uncomfortable conditions occur when cooler air flows predominantly from one direction onto a specific part of the body. A minimum level of air movement is necessary for heat transfer, while increased air velocity is beneficial at higher temperatures as it enhances heat dissipation from the body. A recommended upper limit for air velocity is approximately 0.2 m/s [26].

Table 1 shows a comparison of microclimatic factors in the greenhouse in relation to relevant scientific literature, demonstrating the significance of this research in relation to it.

Table 1. Comparison of microclimatic factors in the greenhouse in relation to the relevant scientific literature.

Microclimate Factors	Key Findings	Interpretation	Literature Support
Air temperature	Air temperature increased during the day, with maximum values at 3 m (up to 29.8 °C), exceeding recommended limits	Heat accumulation due to solar radiation and limited heat dissipation in greenhouse conditions	Heat build-up in enclosed environments is widely reported (Marchetti et al. [9]; Ogunlowo et al. [18]; Boulard and Wang [27])
	Significant effects of measurement height and time ($p < 0.001$)	Vertical stratification of air temperature due to buoyancy effects	Vertical gradients are consistent with microclimate theory (Wróblewski et al. [15]; Oke [28])
	All pairwise time comparisons significant	Pronounced diurnal temperature dynamics	Daily variability confirmed in occupational microclimate studies (Kralikova et al. [12]; Kotek et al. [13])
Relative humidity	Relative humidity decreased during the day (~68% to ~56%)	Inverse relationship between air temperature and relative humidity	Thermodynamic dependence confirmed in indoor climate studies (Chen et al. [19]; ASHRAE [29])
	No significant effect of height; significant effect of time	Temporal variability dominates over spatial variability	Similar findings reported in agricultural environments (Zewdie and Kic [16])
	No difference between midday and afternoon	Stabilisation of microclimate conditions	Observed in greenhouse systems (Ogunlowo et al. [18])

Table 1. Cont.

Microclimate Factors	Key Findings	Interpretation	Literature Support
Air velocity	Higher values at 3 m, lowest at 1 m (0.12 m/s)	Airflow influenced by height and external boundary conditions	Air distribution patterns linked to ventilation and geometry (Wróblewski et al. [15]; Boulard and Wang [27])
	Partial hypothesis confirmation	External wind and thermal gradients affect airflow	External factors highlighted in microclimate studies (Kotek et al. [13])
	No difference between morning and midday	Reduced variability in early day conditions	Comparable patterns observed in industrial environments (Hricova et al. [1])
Occupational implications	Exceedance of prescribed temperature limits	Potential heat stress risk for workers	Occupational safety standards emphasise thermal risk (Parsons [4]; OG, 2020 [21]; ETUC, 2018 [25])
	Daily microclimate variability	Impact on productivity and safety	Strong relationship between microclimate and performance (Kralikova and Wessely [11]; Toşu et al. [14])
	Increasing temperature trends	Climate change intensifies exposure risk	Long-term risks highlighted in occupational studies (Jones et al. [24])
Overall assessment	High variability of all parameters and need for improved control systems	Complex interaction of thermal and airflow processes. Implementation of adaptive/smart control systems recommended	Integrated microclimate approaches required (Ferrante et al. [10]; Graham et al. [17]; Oke [28]). Advanced greenhouse control systems proposed (Chen et al. [19])

2. Materials and Methods

The study investigating the influence of microclimatic factors (air temperature, relative humidity, and air velocity) on the working conditions of workers operating on harvesting platforms was conducted at the company Dalis d.o.o., located in Gajić, Croatia, within a greenhouse used for hydroponic tomato production. The company Dalis d.o.o. was established in 2014 and currently employs 25 workers, with an annual production of approximately 800 tonnes of tomatoes. Their hydroponic greenhouse facilities are situated on a total land area of 25,000 m². The specific greenhouse in which the measurements were conducted has been in operation since 5 May 2019 and covers a total area of 11,800 m² (Figure 1).



Figure 1. Greenhouse used for the investigation as the workplace of a worker operating on a harvesting platform.

The greenhouse is equipped with advanced technology for hydroponic vegetable production, and heating is provided with biomass (wood chips and sawdust). Heating pipes are installed beneath the tomato plants, i.e., between the rows, where they also serve as rails for transport carts and harvesting platforms. Additionally, heating pipes are installed beneath the greenhouse roof, which is particularly important during winter conditions to prevent damage to the greenhouse covering material. The production process is fully automated. The greenhouse microclimate is controlled with a mobile application that allows adjustment of air temperature, relative humidity, air velocity, irrigation, and other parameters relevant to tomato cultivation.

The obligation to assess the working environment arises from occupational safety legislation, with the aim of reducing the risk of occupational diseases. The assessment of the working environment, including the evaluation of microclimatic conditions (air temperature, relative humidity and air velocity), was conducted in accordance with Article 45 of the Occupational Safety Act, as well as the Ordinance on the Testing of the Working Environment and the Ordinance on Occupational Safety for Workplaces.

Measurements of microclimatic parameters were performed using a universal instrument, the METREL POLY MI 6201 Multinorm (Metrel d.d., Horjul, Slovenia, serial number 16050376), together with a microclimatic probe A1091 (Metrel d.d., Horjul, Slovenia) (Table 2) (Figure 2). The measurement method for air temperature, relative humidity and air velocity is conducted at the worker's position, typically at a height of 1–1.20 m above the floor level on which the worker stands; however, measurements may also be performed at other heights depending on the specific characteristics of the workplace. Each measurement must be carried out for at least the duration defined by the time constant of the measuring instrument. All measurements were conducted in accordance with the provisions of the Ordinance on the Testing of the Working Environment (NN 16/16, 120/22).



Figure 2. Instrument for measuring microclimatic factors (METREL POLY MI 6201) with the corresponding microclimatic probe.

During measurements, the instrument records values every second and calculates mean values for each microclimatic parameter (air temperature, relative humidity, and air velocity) over the defined measurement interval. Considering the workplace of a worker operating on a harvesting platform, measurements were conducted at heights of 1 m (Figure 3) and 3 m (Figure 4) above ground level, under typical working conditions. To ensure spatial independence of measurements, six new random locations were selected for each of the three time intervals. Therefore, all 108 observations were treated as statistically independent, justifying the use of standard two-way ANOVA and Kruskal–Wallis tests. Measurements were carried out during three time intervals throughout the day:

1. 08:00–09:00 h;
2. 12:00–13:00 h;
3. 16:00–17:00 h.



Figure 3. Measurement of microclimatic factors in the greenhouse at the workplace of a worker operating on a harvesting platform at a height of 1 m.



Figure 4. Measurement of microclimatic factors in the greenhouse at the workplace of a worker operating on a harvesting platform at a height of 3 m.

Prior to each measurement of microclimatic parameters inside the greenhouse, and in accordance with the defined time intervals, external microclimatic conditions were measured outside the greenhouse. This involved performing three consecutive measurements of outdoor air temperature, relative humidity, and air velocity, followed by the calculation of their arithmetic mean values (Table 3).

Table 2. Technical specifications of the microclimatic probe A1091.

General	Pollution Degree: 2 Weight: 0.04 kg Protection Degree: IP 42		
	Range	Resolution	Accuracy
Air temperature	−20 °C to +60 °C	0.1 °C	±0.2 °C @ 25 °C ±0.5 °C over working range
	Reaction time: $t_{90} = 7.4$ min		
	Measuring method: resistive		
	Working temperature range: −20 °C to +60 °C		
	Maximum humidity: 100%		
Relative humidity	Range	Resolution	Accuracy
	0% to 10%	0.1	±3%
	10% to 90%	0.1	±2%
	90% to 100%	0.1	±3%
	Reaction time: $t_{90} = 15$ s		
	Measuring method: capacitive		
Air velocity	Working temperature range: −20 °C to +60 °C		
	Range	Resolution	Accuracy
	0.10 m/s to 9.99 m/s	0.01 m/s	±0.05 m/s +5% of r.
	10.0 m/s to 20.0 m/s	0.1 m/s	±5% of r.
	Reaction time: $t_{90} < 2$ s		
	Measuring method: HFA method (Hot Film Anemometer)		
	Working temperature range: −20 °C to +60 °C		

Table 3. Measured outdoor microclimatic parameters.

Measurement Time	Air Temperature [°C]	Relative Humidity [%]	Air Velocity [m/s]
08:00–09:00 h	18.7	65.5	1.22
12:00–13:00 h	26.0	50.0	0.73
16:00–17:00 h	28.6	41.0	1.19

Data transfer and processing of the obtained values were performed using the Metrel ES Manager (MESM) software SW 1201. Statistical analysis was conducted using jamovi software (version 2.7). Prior to parametric testing, the assumptions of normality and homogeneity of variances were explicitly evaluated for each variable using the Shapiro–Wilk and Levene’s tests, respectively. Because the data violated the assumption of normality, non-parametric alternatives were employed to validate the robustness of the parametric findings. Specifically, the Mann–Whitney U test was used to compare the two measurement heights, and the Kruskal–Wallis test, followed by Dunn’s post hoc pairwise comparisons with Bonferroni adjustment, was used to compare the three measurement times. The dependent variables were air temperature, relative humidity, and air velocity, while the independent variables were measurement height and measurement time. Boxplots were generated to illustrate the distribution of microclimatic parameters in relation to measurement height and time.

Since the study deals with the determination of microclimatic factors (environmental) in a greenhouse on a worker on a harvesting platform, the ISO 7793 standard [30], which is intended for the assessment of heat stress in working conditions and takes into account relevant factors such as metabolic rate, clothing insulation, duration of exposure and physiological heat stress, was not used; therefore, the study presents a limitation that is mainly based on the assessment of microclimatic environmental parameters and does not represent a complete assessment of physiological heat stress according to the ISO 7933 [30] standard.

3. Results and Discussion

The following tables and boxplots present the measured values of microclimatic factors (air temperature, relative humidity, and air velocity).

Assumption Testing and Non-Parametric Validation

The Shapiro–Wilk test (Table 4) indicated that none of the microclimatic variables followed a normal distribution (temperature: $W = 0.853$, $p < 0.001$; relative humidity: $W = 0.909$, $p < 0.001$; air velocity: $W = 0.793$, $p < 0.001$). Furthermore, Levene’s test (Table 4) revealed significant heterogeneity of variances for temperature and air velocity across measurement heights ($p < 0.05$), and for all variables across measurement times ($p < 0.001$) (Table 4).

Table 4. Results of assumption testing (Shapiro–Wilk and Levene’s tests) for microclimatic variables.

Variable	Shapiro–Wilk W	Shapiro–Wilk p	Levene’s F (Height)	Levene’s p (Height)	Levene’s F (Time)	Levene’s p (Time)
Air temperature	0.853	<0.001	11.0	0.001	9.80	<0.001
Relative humidity	0.909	<0.001	0.535	0.466	20.6	<0.001
Air velocity	0.793	<0.001	28.8	<0.001	9.59	<0.001

Note. Significant p -values ($p < 0.05$) indicate a violation of the assumption.

Due to these violations, non-parametric tests were conducted to confirm the robustness of the parametric ANOVA results. The Mann–Whitney U test confirmed significant differences between measurement heights for temperature ($U = 903$, $p < 0.001$) and air velocity ($U = 901$, $p < 0.001$), but not for relative humidity ($U = 1406$, $p = 0.749$). Similarly, the Kruskal–Wallis test confirmed the significant effect of measurement time on temperature ($\chi^2 = 78.6$, $p < 0.001$, $\epsilon^2 = 0.735$), relative humidity ($\chi^2 = 71.4$, $p < 0.001$, $\epsilon^2 = 0.667$), and air velocity ($\chi^2 = 18.1$, $p < 0.001$, $\epsilon^2 = 0.169$). Dunn’s post hoc tests yielded pairwise comparisons fully consistent with Tukey’s HSD results. Consequently, the original ANOVA findings are considered robust and valid despite the assumption violations.

The results of the descriptive statistics related to the mean values of the microclimatic factor air temperature indicate that the highest values were recorded at a height of 3 m across all measurement times, except during the 08:00–09:00 h interval, when the highest value was observed at a height of 1 m. Conversely, the lowest values were recorded at a height of 1 m for all measurement times, except during the 08:00–09:00 h interval, when the lowest value was measured at a height of 3 m (20.9833 °C) (Table 5). The research hypothesis, stating that air temperature values increase with the working day, was confirmed, which is consistent with the trend observed in outdoor air temperature, which also increased during the day (first: 18.7 °C, second: 26.0 °C, and third: 28.6 °C). Although the greenhouse is equipped with an automated temperature-control system, the recorded values exceeded the permissible limits defined by occupational safety regulations. This is presumably due

to solar radiation penetrating the greenhouse covering, resulting in the heating of plants, soil, and internal surfaces, combined with limited heat dissipation outside the greenhouse.

Table 5. Descriptive statistics of mean values of the microclimatic factor air temperature.

Measurement Height	Measurement Time	Mean Value [°C]	Std. Deviation	N
1	08:00–09:00	21.0111	0.83447	18
	12:00–13:00	26.6167	0.25263	18
	16:00–17:00	27.4278	0.57477	18
	Total	25.0185	2.93984	54
2	08:00–09:00	20.9833	0.85009	18
	12:00–13:00	28.2056	0.81995	18
	16:00–17:00	29.7889	0.36924	18
	Total	26.3259	3.93164	54
Total	08:00–09:00	20.9972	0.83031	36
	12:00–13:00	27.4111	1.00336	36
	16:00–17:00	28.6083	1.28849	36
	Total	25.6722	3.51695	108

Although Table 5 presents means and standard deviations for descriptive purposes, the non-parametric analyses were based on medians and interquartile ranges, which are reported in the boxplot descriptions (Figures 5–7).

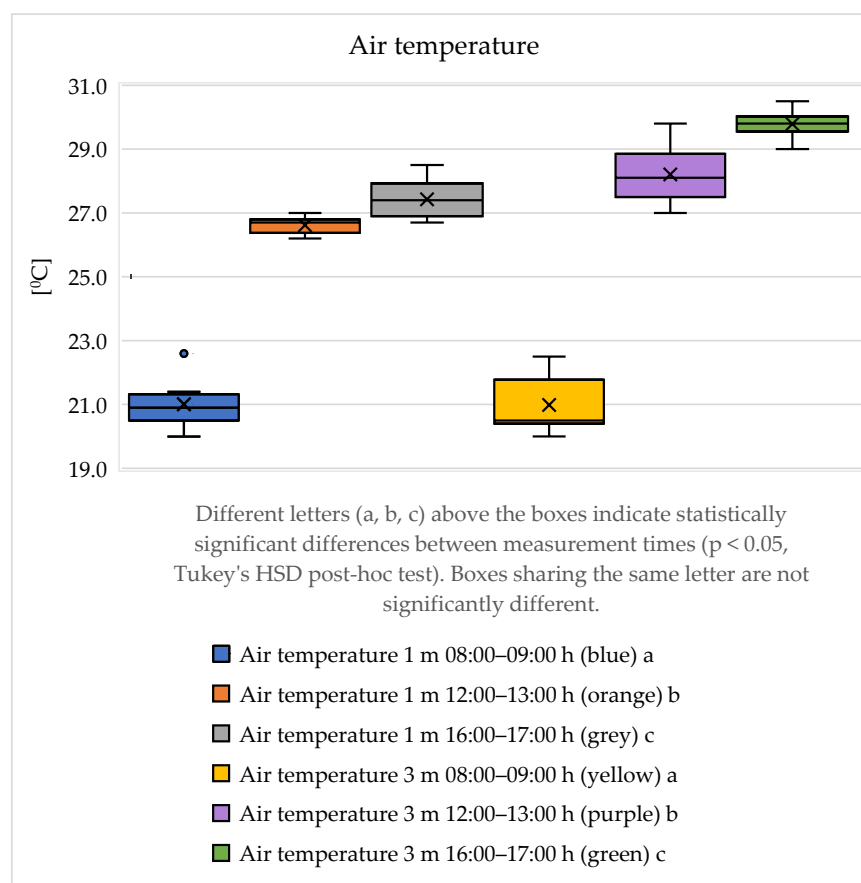


Figure 5. Boxplots of the microclimatic factor air temperature in relation to independent variables.

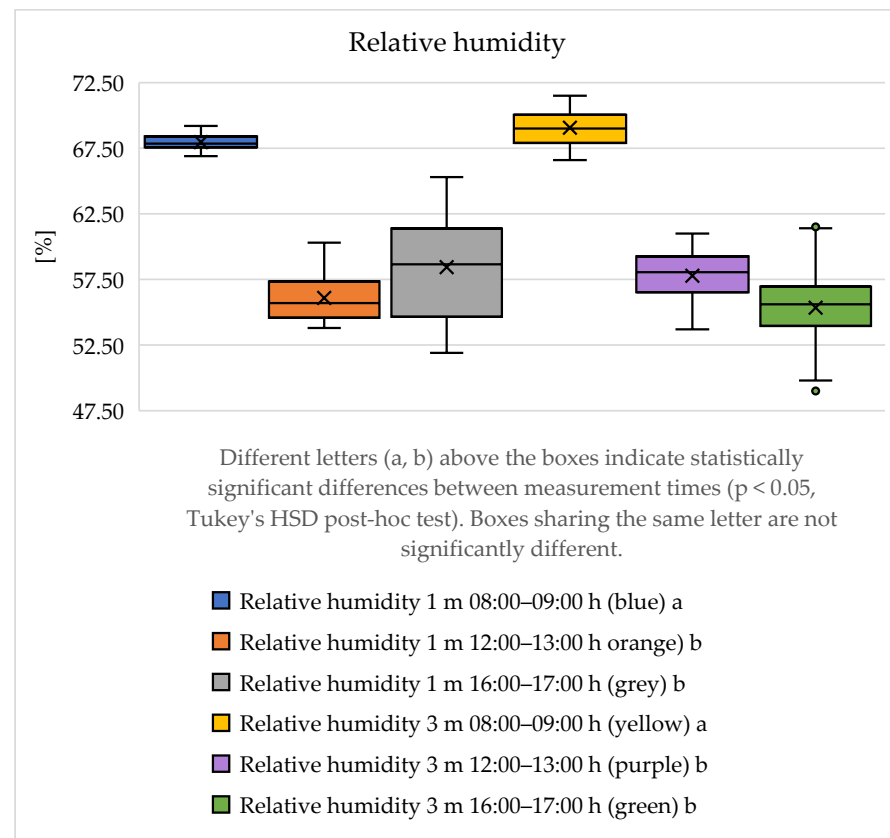


Figure 6. Boxplots of the microclimatic factor relative humidity in relation to independent variables.

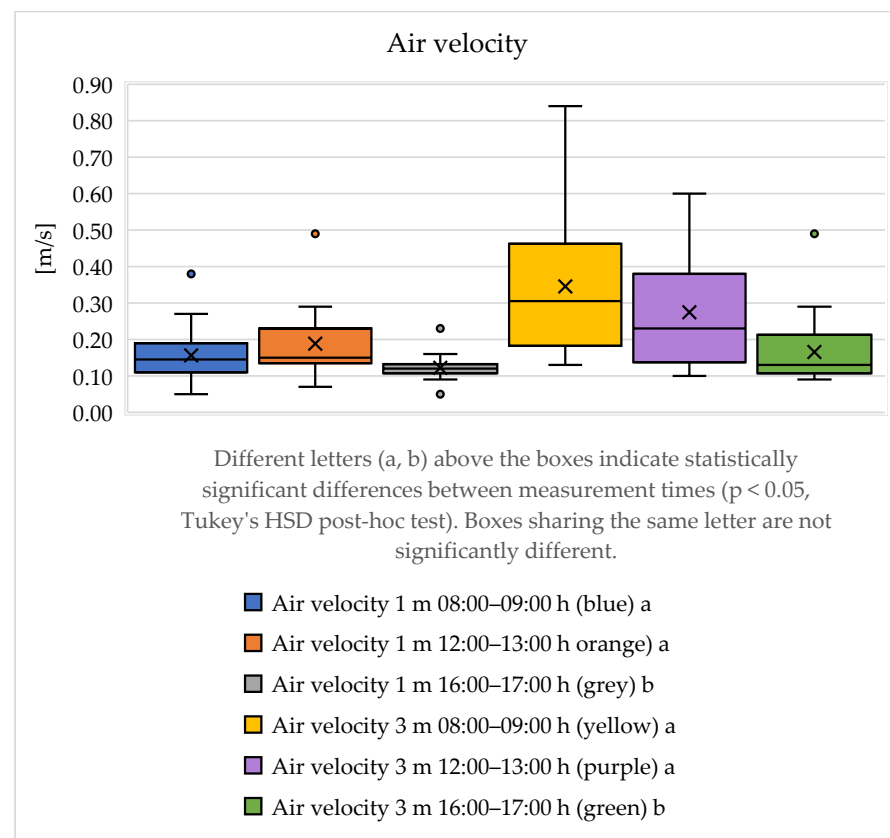


Figure 7. Boxplots of the microclimatic factor air velocity in relation to independent variables.

Analysis of variance (ANOVA) revealed statistically significant differences in the mean values of air temperature with respect to measurement height, measurement time, and their interaction (Table 6).

Table 6. Analysis of variance of the microclimatic factor air temperature in relation to independent variables (ANOVA).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1278.906 ^a	5	255.781	585.349	0.000	0.966
Intercept	71,178.803	1	71,178.803	162,891.114	0.000	0.999
Measurement height	46.151	1	46.151	105.617	0.000	0.509
Measurement time	1206.004	2	603.002	1379.957	0.000	0.964
Measurement height Measurement time	26.750	2	13.375	30.609	0.000	0.375
Error	44.571	102	0.437			
Total	72,502.280	108				
Corrected Total	1323.477	107				

^a R Squared = 0.966 (Adjusted R Squared = 0.965).

Multiple comparisons of air temperature across measurement times, using Tukey's HSD, showed statistically significant differences for all combinations of measurement times (Table 7).

Table 7. Multiple comparisons of the microclimatic factor air temperature in relation to independent variables.

	(I) Measurement Time	(J) Measurement Time	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	08:00–09:00	12:00–13:00	−6.4139 *	0.15581	0.000	−6.7845	−6.0433
		16:00–17:00	−7.6111 *	0.15581	0.000	−7.9817	−7.2405
	12:00–13:00	08:00–09:00	6.4139 *	0.15581	0.000	6.0433	6.7845
		16:00–17:00	−1.1972 *	0.15581	0.000	−1.5678	−0.8266
	16:00–17:00	08:00–09:00	7.6111 *	0.15581	0.000	7.2405	7.9817
		12:00–13:00	1.1972 *	0.15581	0.000	0.8266	1.5678

* The mean difference is significant at the 0.05 level. Based on observed means. The error term is Mean Square (Error) = 0.437.

The effect size analysis revealed that measurement time had the strongest influence on air temperature (partial $\eta^2 = 0.964$), representing an exceptionally large effect. This indicates that approximately 96.4% of the variance in air temperature was explained by the time of measurement after controlling for the other factors included in the model. Such a high effect size demonstrates that the diurnal progression of the working day was the dominant determinant of greenhouse air temperature. The effect of measurement height was also very large (partial $\eta^2 = 0.509$), indicating that approximately 50.9% of the variance in air temperature was attributable to differences between the two measurement heights. This finding confirms the presence of pronounced vertical thermal stratification within the greenhouse. Furthermore, the interaction between measurement height and measurement time showed a large effect (partial $\eta^2 = 0.375$), indicating that the influence of measurement time varied according to measurement height. This result suggests that the increase in air temperature during the day was not uniform throughout the greenhouse.

but depended on vertical position (Table 6). These parametric results were validated by a non-parametric Kruskal–Wallis test, which confirmed the significant effect of measurement time on temperature ($\chi^2 = 78.6$, $p < 0.001$, $\epsilon^2 = 0.735$), demonstrating the robustness of the findings despite violations of normality assumptions.

The highest values of the microclimatic factor relative humidity were recorded at a height of 1 m across all measurement times, except during the first time interval (08:00–09:00 h), when the value was 58.4389%. The lowest relative humidity value was measured at a height of 3 m during the 16:00–17:00 h interval (55.3444%) (Table 8). A decreasing trend in relative humidity within the greenhouse was observed throughout the working day, which is consistent with the research hypothesis that relative humidity decreases over time. This trend corresponds with the decline in outdoor relative humidity during the day (first: 65.5%, second: 50.0%, and third: 41.0%). Although plants release moisture through stomatal transpiration, the increase in air temperature during the working day has a dominant effect on reducing relative humidity, as also demonstrated in this study.

Table 8. Descriptive statistics of mean values of the microclimatic factor relative humidity.

Measurement Height	Measurement Time	Mean Value [%]	Std. Deviation	N
1	08:00–09:00	67.9667	0.66155	18
	12:00–13:00	56.0944	1.77647	18
	16:00–17:00	58.4389	4.21693	18
	Total	60.8333	5.80621	54
2	08:00–09:00	69.0611	1.41884	18
	12:00–13:00	57.7833	2.00829	18
	16:00–17:00	55.3444	3.50130	18
	Total	60.7296	6.49948	54
Total	08:00–09:00	68.5139	1.22408	36
	12:00–13:00	56.9389	2.05555	36
	16:00–17:00	56.8917	4.12964	36
	Total	60.7815	6.13396	108

Although Table 8 presents means and standard deviations for descriptive purposes, the non-parametric analyses were based on medians and interquartile ranges, which are reported in the boxplot descriptions (Figures 5–7).

Statistically significant differences in mean values of relative humidity were observed only with respect to measurement time and the interaction between the independent variables (measurement height and measurement time), while measurement height alone did not show a significant effect (Table 9).

Multiple comparisons of relative humidity across measurement times, using Tukey's HSD, revealed statistically significant differences for all combinations except between time intervals 2 (12:00–13:00 h) and 3 (16:00–17:00 h), and vice versa (Table 10).

For relative humidity, measurement time produced an exceptionally large effect (partial $\eta^2 = 0.827$), explaining approximately 82.7% of the variance in relative humidity. This indicates that the temporal progression of the working day was the primary factor influencing humidity conditions inside the greenhouse. In contrast, measurement height showed a negligible effect (partial $\eta^2 \approx 0.000$), confirming that differences in measurement height contributed virtually nothing to the observed variation in relative humidity. This finding is consistent with the non-significant ANOVA result ($p = 0.834$). The interaction between

measurement height and measurement time exhibited a large effect (partial $\eta^2 = 0.154$), suggesting that although measurement height alone was not influential, the daily pattern of humidity changed differently at the two measurement heights (Table 9). The Kruskal–Wallis test confirmed these findings, showing a significant effect of measurement time on relative humidity ($\chi^2 = 71.4$, $p < 0.001$, $\varepsilon^2 = 0.667$), with post hoc Dunn tests revealing the same pattern of pairwise differences as Tukey’s HSD.

Table 9. Analysis of variance of the microclimatic factor relative humidity in relation to independent variables (ANOVA).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3351.339 ^a	5	670.268	101.347	0.000	0.832
Intercept	398,993.957	1	398,993.957	60,329.561	0.000	0.998
Measurement height	0.290	1	0.290	0.044	0.834	0.000
Measurement time	3228.707	2	1614.353	244.097	0.000	0.827
Measurement height Measurement time	122.341	2	61.171	9.249	0.000	0.154
Error	674.584	102	6.614			
Total	403,019.880	108				
Corrected Total	4025.923	107				

^a R Squared = 0.832 (Adjusted R Squared = 0.824).

Table 10. Multiple comparisons of the microclimatic factor relative humidity in relation to independent variables.

	(I) Measurement Time	(J) Measurement Time	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	08:00–09:00	12:00–13:00	11.5750 *	0.60615	0.000	10.1333	13.0167
		16:00–17:00	11.6222 *	0.60615	0.000	10.1805	13.0639
	12:00–13:00	08:00–09:00	−11.5750 *	0.60615	0.000	−13.0167	−10.1333
		16:00–17:00	0.0472	0.60615	0.997	−1.3945	1.4889
	16:00–17:00	08:00–09:00	−11.6222 *	0.60615	0.000	−13.0639	−10.1805
		12:00–13:00	−0.0472	0.60615	0.997	−1.4889	1.3945

* The mean difference is significant at the 0.05 level. Based on observed means. The error term is Mean Square (Error) = 6.614.

Descriptive statistics of the mean values of the microclimatic factor air velocity indicate that the highest values were recorded at a height of 3 m across all measurement times, while the lowest value was observed at a height of 1 m during the third time interval (0.1222 m/s) (Table 11). The results for air velocity did not fully support the initial research hypothesis. This may be attributed to the reduced temperature gradient between indoor and outdoor environments, which significantly influences air movement, as well as to external wind conditions, which varied with the day (first interval: 1.22 m/s, second interval: 0.73 m/s, third interval: 1.19 m/s).

Although Table 11 presents means and standard deviations for descriptive purposes, the non-parametric analyses were based on medians and interquartile ranges, which are reported in the boxplot descriptions (Figures 5–7).

Analysis of variance (ANOVA) revealed statistically significant differences in the mean values of air velocity with respect to measurement height, measurement time, and their interaction (Table 12).

Table 11. Descriptive statistics of mean values of the microclimatic factor air velocity.

Measurement Height	Measurement Time	Mean Value [m/s]	Std. Deviation	N
1	08:00–09:00	0.1561	0.08103	18
	12:00–13:00	0.1883	0.09482	18
	16:00–17:00	0.1222	0.03606	18
	Total	0.1556	0.07842	54
2	08:00–09:00	0.3456	0.19800	18
	12:00–13:00	0.2744	0.15155	18
	16:00–17:00	0.1656	0.09805	18
	Total	0.2619	0.16914	54
Total	08:00–09:00	0.2508	0.17737	36
	12:00–13:00	0.2314	0.13202	36
	16:00–17:00	0.1439	0.07606	36
	Total	0.2087	0.14166	108

Table 12. Analysis of variance of the microclimatic factor air velocity in relation to independent variables (ANOVA).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	0.640 ^a	5	0.128	8.668	0.000	0.298
Intercept	4.704	1	4.704	318.415	0.000	0.757
Measurement height	0.305	1	0.305	20.649	0.000	0.168
Measurement time	0.234	2	0.117	7.908	0.001	0.134
Measurement height Measurement time	0.102	2	0.051	3.437	0.036	0.063
Error	1.507	102	0.015			
Total	6.851	108				
Corrected Total	2.147	107				

^a R Squared = 0.298 (Adjusted R Squared = 0.264).

Multiple comparisons of air velocity across measurement times, using Tukey's HSD, indicated statistically significant differences for all combinations except between time intervals 1 (08:00–09:00 h) and 2 (12:00–13:00 h), and vice versa (Table 13).

For air velocity, measurement height produced the largest effect (partial $\eta^2 = 0.168$), representing a large effect size and indicating that approximately 16.8% of the variance in air velocity was explained by differences in measurement height. This finding confirms the existence of vertical airflow gradients within the greenhouse. The effect of measurement time was also substantial (partial $\eta^2 = 0.134$), representing a medium-to-large effect. Approximately 13.4% of the variance in air velocity was explained by the time of measurement, demonstrating that airflow conditions changed throughout the working day. The interaction between measurement height and measurement time showed a moderate effect

(partial $\eta^2 = 0.063$), indicating that temporal changes in air velocity differed slightly between measurement heights, although this interaction was considerably weaker than those observed for air temperature and relative humidity (Table 12). Non-parametric analysis using the Kruskal–Wallis test supported these results ($\chi^2 = 18.1$, $p < 0.001$, $\epsilon^2 = 0.169$), with Dunn’s pairwise comparisons confirming significant differences between time 1 vs. 3 and time 2 vs. 3, but not between time 1 vs. 2.

Table 13. Multiple comparisons of the microclimatic factor air velocity in relation to independent variables.

	(I) Measurement Time	(J) Measurement Time	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	08:00–09:00	12:00–13:00	0.0194	0.02865	0.776	−0.0487	0.0876
		16:00–17:00	0.1069 *	0.02865	0.001	0.0388	0.1751
	12:00–13:00	08:00–09:00	−0.0194	0.02865	0.776	−0.0876	0.0487
		16:00–17:00	0.0875 *	0.02865	0.008	0.0194	0.1556
	16:00–17:00	08:00–09:00	−0.1069 *	0.02865	0.001	−0.1751	−0.0388
		12:00–13:00	−0.0875 *	0.02865	0.008	−0.1556	−0.0194

* The mean difference is significant at the 0.05 level. Based on observed means. The error term is Mean Square (Error) = 0.015.

Boxplots (Figures 5–7) illustrate both central tendency and distribution patterns of the microclimatic factors (air temperature, relative humidity and air velocity) in relation to measurement height and time. As shown in Figure 5, the lowest median values of air temperature were observed during the first time interval (08:00–09:00 h) at both heights of 1 m (21.0 °C) and 3 m (21.0 °C), while the highest median was recorded during the third time interval (16:00–17:00 h) at a height of 3 m (29.8 °C).

Furthermore, the lowest data dispersion for air temperature was observed at a height of 1 m during the second time interval (12:00–13:00 h), and at a height of 3 m during the third time interval (16:00–17:00 h). The highest dispersion was observed at a height of 3 m during the first (08:00–09:00 h) and second (12:00–13:00 h) time intervals.

The presented values of the microclimatic factor relative humidity (Figure 6) indicate that the lowest median (55.34%) was recorded at a height of 3 m during the third time interval (16:00–17:00 h), while the highest median (69.06%) was observed at the same height during the first time interval (08:00–09:00 h). The lowest data dispersion was identified at a height of 1 m during the first time interval (08:00–09:00 h), whereas the highest dispersion was observed at the same height during the third time interval (16:00–17:00 h).

Boxplots of the microclimatic factor air velocity (Figure 7) show that the lowest median (0.12 m/s) and the lowest data dispersion were recorded at a height of 1 m during the third time interval (16:00–17:00 h). In contrast, the highest median (0.35 m/s) and the greatest data dispersion were observed at a height of 3 m during the first time interval (08:00–09:00 h).

The results demonstrate a pronounced diurnal variability of greenhouse microclimate parameters, with air temperature increasing and relative humidity decreasing over the course of the working day. Significant effects of measurement height, time, and their interaction confirm the presence of vertical stratification and dynamic microclimate behaviour. These findings are consistent with established microclimate theory and previous studies in controlled agricultural environments. Exceeding the recommended temperature limits indicates a potential risk of heat stress for workers, which highlights the need for improved microclimate management strategies. In this context, the implementation of advanced or adaptive management systems is essential to ensure occupational safety and optimal environmental conditions. A summary of the results with explanations is presented in Tables 14 and 15.

Table 14. Summary of results of microclimatic factors in the greenhouse with discussion and explanations.

Microclimatic Factor	Main Findings	Statistical Significance	Potential Practical Methods for Reducing Work-Related Stress Factors
Air temperature	Air temperature increased throughout the working day and exceeded the recommended occupational exposure limits during the afternoon. The highest values were recorded at a height of 3 m.	Significant effects of measurement height, measurement time, and their interaction ($p < 0.001$). Significant effects were confirmed by both ANOVA ($p < 0.001$) and the Kruskal–Wallis test ($\chi^2 = 78.6$, $p < 0.001$).	Implementation of automated ventilation and shading systems, evaporative cooling or misting, scheduling physically demanding tasks during cooler periods of the day, providing more frequent rest breaks, ensuring adequate hydration, and rotating workers to reduce heat exposure.
Relative humidity	Relative humidity decreased throughout the working day, corresponding to the increase in air temperature. Measurement height alone did not significantly affect humidity.	Significant effects of measurement time and the interaction between height and time ($p < 0.001$), while measurement height alone was not significant ($p = 0.834$). Significant effects were confirmed by both ANOVA ($p < 0.001$) and the Kruskal–Wallis test ($\chi^2 = 71.4$, $p < 0.001$).	Optimisation of natural and mechanical ventilation, automated control of ventilation openings, appropriate irrigation management, and regulation of evapotranspiration to maintain favourable indoor humidity conditions.
Air velocity	The highest air velocities were recorded at a height of 3 m, while the lowest values occurred at 1 m during the afternoon. The initial hypothesis regarding air velocity variation during the working day was only partially confirmed.	Significant effects of measurement height, measurement time, and their interaction ($p < 0.05$). No significant difference was found between the morning and midday measurements. Significant effects were confirmed by both ANOVA ($p < 0.05$) and the Kruskal–Wallis test ($\chi^2 = 18.1$, $p < 0.001$).	Improvement of natural or mechanical ventilation, optimisation of fan placement, adjustment of ventilation openings, and implementation of adaptive airflow management according to outdoor weather conditions.
Overall microclimate assessment	The greenhouse microclimate exhibited pronounced diurnal variation: air temperature increased, relative humidity decreased, and air velocity varied depending on measurement height and time. Vertical stratification of the indoor environment was observed, and elevated temperatures indicated a potential risk of occupational heat stress.	The results confirmed a significant influence of measurement time on all three microclimatic parameters. The robustness of these findings was confirmed through parallel non-parametric analyses (Mann–Whitney U and the Kruskal–Wallis tests), which yielded results consistent with the parametric ANOVA, thereby validating the conclusions despite assumption violations.	Implementation of an integrated greenhouse climate management system combining automated ventilation, shading, and cooling technologies; continuous environmental monitoring using sensor networks; adaptation of work schedules; and worker education on heat stress prevention and hydration practices.

Table 15. Summary of results of microclimatic factors in the greenhouse with Justification for measurement method and thermal comfort.

Microclimatic Factor	Justification for the Selected Measurement Method	Relationship with WBGT/PMV, Productivity Risk and Practical Implications
Air temperature	Air temperature was measured in situ at two representative working heights and during three time intervals, allowing the assessment of actual conditions experienced by workers. Compared with modelling approaches or single-point measurements frequently reported in the literature, this method provides a more realistic evaluation of both spatial and temporal microclimatic variability.	Air temperature is the principal variable influencing both WBGT and PMV. The observed afternoon temperatures indicate an increased probability of heat stress, higher PMV values (warmer thermal sensation), and elevated WBGT levels that may exceed recommended occupational thresholds. These conditions are associated with reduced work capacity, increased fatigue, impaired cognitive performance, and productivity losses. Engineering controls (ventilation, shading, evaporative cooling) combined with administrative controls (work–rest cycles and hydration) are therefore recommended.
Relative humidity	Simultaneous measurement of relative humidity and air temperature enables evaluation of their combined influence on thermal stress. This approach provides a more reliable assessment than evaluating a single microclimatic parameter alone.	Relative humidity directly affects evaporative heat loss and therefore influences both WBGT and PMV. Lower afternoon humidity may improve sweat evaporation, but when accompanied by high air temperatures, the overall thermal load remains considerable. Maintaining an optimal balance between temperature and humidity improves worker comfort and helps preserve productivity.
Air velocity	Air velocity was measured directly using an anemometer at representative working heights, providing an accurate assessment of ventilation effectiveness and worker exposure. Unlike theoretical calculations or computational fluid dynamics (CFD) simulations, direct field measurements provide experimental data suitable for occupational risk assessment.	Air velocity is an important component of PMV and indirectly affects WBGT by enhancing convective and evaporative cooling. The relatively low air velocities measured near workers reduce heat dissipation, thereby increasing perceived thermal discomfort and physiological strain. Improving airflow can reduce heat stress without substantially increasing energy consumption.
Overall microclimate assessment	The selected methodology was based on direct measurements of air temperature, relative humidity, and air velocity at representative working heights and at different times of the working day, enabling a comprehensive assessment of actual worker exposure. Compared with approaches relying solely on thermal comfort or heat stress indices (e.g., WBGT, PMV, or PPD), direct measurement of individual microclimatic parameters provides a more detailed understanding of their spatial distribution, temporal variability, and combined effects within the greenhouse environment, thereby offering a stronger basis for occupational risk assessment and the development of effective preventive measures.	Although this study focused on direct measurements of individual microclimatic parameters, the results clearly indicate conditions that would likely correspond to moderate to high heat stress according to WBGT and positive PMV values ($> +2$) during the afternoon. Such conditions are associated with measurable reductions in labour productivity, increased physiological strain, and greater occupational risk. Consequently, implementing engineering controls (ventilation, shading, cooling technologies) together with administrative measures (work–rest schedules, task rescheduling, hydration protocols) is expected to substantially reduce heat stress and maintain worker productivity.

4. Conclusions

This study provides insight into the influence of microclimatic factors (air temperature, relative humidity, and air velocity) on the working conditions of workers operating on harvesting platforms. It also establishes a foundation for further research and the development of systems aimed at ensuring more stable and favourable microclimatic conditions in protected agricultural production environments.

The conducted research led to the following conclusions:

- The highest air temperature was recorded during the third time interval (16:00–17:00 h) at a height of 3 m (29.7889 °C). According to occupational safety regulations, this value exceeds the optimal working temperature range of 20–25 °C. The most favourable temperature profile was observed during the first time interval (08:00–09:00 h) at heights of 1 m (21.0111 °C) and 3 m (20.9833 °C).
- The highest relative humidity values were recorded during the first time interval at heights of 1 m (67.9667%) and 3 m (69.0611%), whereas all other values across measurement times and heights remained within or below the recommended range (30–60%) defined by occupational safety regulations.
- Air velocity values did not exceed the prescribed limits (0.6 m/s and 0.8 m/s) according to occupational safety regulations at any measurement time or height.
- Statistical analysis (two-way ANOVA, validated by non-parametric Mann–Whitney U and Kruskal–Wallis tests due to assumption violations) confirmed, in most cases, significant differences between treatments across all three microclimatic factors, largely supporting the research hypothesis that air temperature increases with the working day, while relative humidity and air velocity decrease.
- In Croatia, greenhouse work is generally classified as heavy physical labour. Considering that air temperature and relative humidity exceed recommended limits with the working day, these conditions represent a potential health risk for workers.
- To mitigate the identified occupational heat stress risks, the following specific recommendations are proposed for greenhouse management and occupational health and safety (OHS) practices. (a) Task Scheduling: Physically demanding activities, such as harvesting and manual transport of crates, should be scheduled during the morning hours (08:00–09:00 h) when microclimatic conditions are most favourable, and temperatures are within the optimal range (approx. 21 °C). (b) Targeted Ventilation and Airflow: Since heat accumulates significantly at higher levels (up to 29.8 °C at 3 m), automated roof ventilation and shading systems should be activated proactively before the midday peak. Additionally, horizontal airflow (HAF) fans should be employed to increase air velocity at the worker level (1 m), thereby enhancing convective cooling and sweat evaporation. (c) Administrative Controls: Mandatory work–rest cycles, acclimatization protocols, and increased hydration breaks must be strictly enforced during the afternoon shifts (12:00–17:00 h) to protect workers from heat-related fatigue and health risks.
- Future research should expand this study by including a larger number of greenhouses (of varying sizes), systems with and without automated microclimate control, and different crop types. Additionally, monitoring the health status of workers operating on harvesting platforms would enable the development of evidence-based guidelines for greenhouse production and the establishment of optimal working conditions.
- The study has a limitation as it is based on the assessment of environmental microclimatic parameters and does not represent a complete assessment of the physiological heat stress of workers in a greenhouse on a harvesting platform. Therefore, future research would be aimed at determining the assessment of worker heat stress.

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