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Microclimatic Control in Confined Agricultural Environment for Plants Cultivation

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Microclimatic control is having an increasingly widespread in confined agricultural environment. This is important especially for plants cultivations that tolerate thermal and hygrometric conditions significantly different. Nevertheless, there is much to do in automation and control technologies of this field to achieve the best results in both quantitative and qualitative terms of the products. This is true above all for horticultural crops, sensible to pedoclimatic and microclimatic environment of cultivation. Aim of this work is to characterize the microclimatic parameters in a confined agricultural environment with a perforated duct for the supply of the air conditioning. For this work a microclimatic control unit was used instead of lettuce plants. It was placed into a confined agricultural environment at different locations in the space to acquire the main microclimatic parameters. After setting the inputs of the microclimate environment, the tool measured a series of physical quantities (temperature, radiant temperature, humidity, and air speed). Tests were carried out taking as constant the optimal day temperature to grow lettuce, and by varying supply airflow rate, setting the fan speed at 30 %, 50 %, and 80 %. The results of these tests are essential to perform a real-time control of the microclimatic environment and to manage parameters for the optimization of the entire system. In addition, air speed tests showed an adequate speed decay and a good mixing of air. The values obtained are generally acceptable for indoor cultures and the created conditions are suitable for plants cultivation in this kind of environment.

1. Introduction

In the last few decades, the demand of food supply is increasing because of exponentially growing of human population and climatic changes make increasingly difficult to satisfy this request (Nellemann et al., 2009; Staniškis, 2012; Fedoroff, 2015) Thus, it is evident and pressing the need of a new approach in agricultural practices and food technologies. However, the development of new solutions in the food supply chain cannot be separated from a careful assessment of the energy saving aspects, both in the cropping phase (Perone et al., 2017a; Perone et al., 2020) and in the transformation processes (Perone et al., 2017b; Catalano et al., 2020). In particular, to improve agriculture efficiency different techniques can be used to adapt the environment agriculture condition to plant needs and, in this way, to extend the harvest time of cultivations. One of the common solutions is represented by greenhouse, and the studying of it management enhanced the importance of microclimatic control in agricultural environments (Perone et al., 2017a; Ma et al., 2019). The handling of microclimatic parameters and the isolation from outdoor environment impose the utilization of innovative techniques beside conventional agriculture.

New concepts are emerging from the broader strand of Urban Agriculture (UA) or Urban Farming (UF), as an increasingly relevant topic in planning of urban food systems aimed at reducing food supply issue and projected to the dimensions of economic, social, and environmental sustainability (Orsini et al, 2013). The UA sphere includes the Controlled Agriculture Environment (CEA) concept, that, thanks to its innovative techniques, fit well in the research of sustainable cultivation technologies. Nowadays it is widely spreading

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(Shamshiri et al., 2018), which design and methods of environmental control can vary greatly depending on where it is located (Jensen, 2001). CEA systems are characterized by a clear separation between controlled agriculture environment (indoor) and the external uncontrolled environment (outdoor), even if the outdoor characteristics are taken in account to better control indoor and damping the diurnal and seasonal climatic variation of outdoor (Abdullah et al., 2016). Thus, in controlled agricultural environments with microclimate management, variability of outdoor environment does not affect plants cultivation and indoor microclimatic parameters can be controlled independently, allowing a greater harvest efficiency. It is clear that in CEA the optimal control of indoor microclimatic conditions becomes the key factor to increase the productivity and promote plants growth and health (Heuvelink and Gonzalez-Real, 2008; Nicholsa, 2017). In fact, anomalous alteration of the microclimate can induce morphological and physiological modifications of plants as result of environment-plant interaction (Amitrano et al., 2019).

In this scenario, the monitoring and managing of microclimatic parameters becomes of primary importance and it is essential to consider control systems and locations inside the closed agricultural environment (Wada et al., 2019). In particular, lighting and air conditioning represent the main key factors in agricultural environment microclimate, through which it is possible to work directly and indirectly on crops quantitative and qualitative parameters (Yeh and Chung, 2009; Goto, 2012).

The aim of this paper is to evaluate the distribution of the microclimatic parameters in a confined agricultural environment conditioned by supplying treated air with a perforated duct. The air conditioning system was handled to ensure the microclimatic parameters of a CEA for successive lettuce plants cultivation. This purpose is obtained using a microclimatic control unit, which simulate the crop. The measures of temperature, humidity, globe thermometer temperature, and air speed, were performed at different fan speeds for air conditioning supplying.

2. Materials and methods

2.1 Equipment

Tests for microclimatic parameters characterization were conducted in a closed environment with an inner volume of 40 m^3 and with dimensions of 4.1 x 3.6 x 2.7 m (Width x Depth x Height) (Figure 1). The environment was insulated on the perimeter walls and on the roof with sandwich panels composed of 4.0 cm of polyurethane foam.

A handling unit of 500 m^3/h provide the conditioned air supplied by a perforated duct of 0.25 m in diameters and 3 m in length, with a 5 series of circular holes of different size. A central row of holes has a size of 20 mm and has the main aim of providing the air flow rate. Two rows of 10 mm holes on each side of the central row generates the induction phenomenon. The duct was installed on one side of the environment at a height of 2.30 m. A recovery grid is located in the corner on the opposite side of the supply duct, at a height of about 60 cm. The relative humidity of the environment was adjusted by supplying water vapor produced by an immersed electrode steam humidifier, with a nominal water vapor rate of 3 kg/h.

Measuring the recovery temperature T_R (probe installed on the recovery side of the handling unit) and the room humidity (U_{CTR}) (with a combined T-RH probe located at the centre of the environment), it was possible to regulate the handling unit and the humidifier to stabilize the indoor microclimatic parameters.

A supervision system allowed the data acquisition and historicization thanks to a set of probes (Table 1) and a microclimatic control unit that was used instead of lettuce plants.

2.2 Microclimatic parameters acquisition

The microclimatic control unit was placed at nine different locations equally distributed into the controlled agricultural environment, with a distance from walls of 0.90 cm, as shown in Figure 1, to have a uniform characterization of microclimatic parameters of the closed environment. It was equipped with probes for the acquisition of the main microclimatic dimension (temperature, radiant temperature, humidity, and air speed) and fixed at a height of 1.05 m, simulating the height of a shelf for the positioning of plants and/or of ~~an~~ typical aeroponic system.

Table 1 shows the characteristics of the probes used for the measurement tests. The brand of all the probes is Centraline by Honeywell, except for the globe thermometer which is LSI LASTEM.

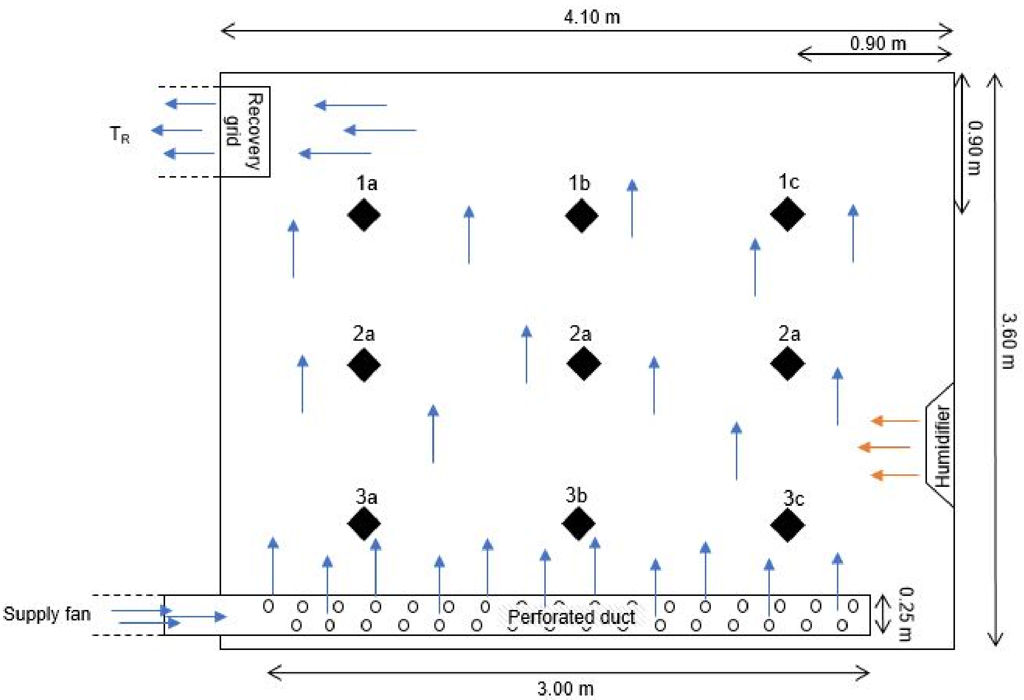

Figure 1: spatial locations for data acquisition in the controlled agricultural environment, equipped with a supply fan, a perforated duct, a recovery grid, and a humidifier.

It was chosen an environment set-point temperature of 21 °C as constant day temperature for an optimum growth of lettuce crop, with a dead band of ± 1 °C. Also the internal humidity was chosen according the optimal growing of lettuce and fixed at 70 % ± 5 %.

Tests were carried out setting the fan (ebm-papst K3G 190, with M3G055 – BI electronic motor) at different airflow speed rates: 30 %, 50 %, and 80 % of maximum fan speed. When the system reached the regime, all the data characterizing the indoor microclimate were acquired for each of the nine space positions, for an acquisition time of 5 minutes. This represents a sufficient time to have a good insight on the local conditions. The sampling time for each parameter was set to 5 seconds.

The acquired data were downloaded in spreadsheet format on a personal computer when data acquisition is completed.

Table 1: Probes used during experimental tests.

Probes	Accuracy
Humidity and Temperature Room Sensors, range 5–95% -30 − 70 °C, output 0–10 Vcc	±0.2 K at 25 °C
	±3 % at 25 °C 30–70 % rh
	±5 % at 25 °C 10–30 % 70–90 % rh
	±10 % at 25 °C 5–10 % 90–95 % rh
Globe thermometric probe, range -30 – 70 °C	0.15 °C
Duct humidity-temperature sensor, range 5–95% 30–70°C, output 0–10 Vcc	±0.3 K at 25 °C
	±2.5 % at 20 °C 10–95 % rh
Hot wire anemometer, range 0–20 m/s, -50 +50 °C	<10 %

3. Results and Discussion

The acquired data were elaborated to analyse the distributions of the physical parameters inside the controlled environment. These estimations are based on the reasonable hypothesis that, at regime, the physical conditions of the environment are almost constant. Thus, it is possible to affirm that the temporal mean of all the acquired data of each probes is a reasonable estimation of the measured parameters and that the standard deviation can be assumed as its uncertainty.

Table 2: Average values and standard deviation of measured parameters at 30 % airflow speed.

		1a	1b	1c	2a	2b	2c	3a	3b	3c
T_{CTR} [°C]	$\bar{x}$	24.66	25.39	25.00	24.51	25.27	24.83	25.45	25.11	24.68
	σ	0.05	0.06	0.04	0.04	0.06	0.04	0.05	0.03	0.04
U_{CTR} [%]	$\bar{x}$	73.28	67.41	66.46	71.29	71.04	69.17	65.05	67.62	73.71
	σ	2.87	1.44	2.01	4.27	1.94	0.13	1.63	3.31	0.52
T_{cr} [°C]	$\bar{x}$	23.80	24.27	24.00	23.69	24.11	23.78	24.30	24.13	23.95
	σ	0.03	0.05	0.04	0.08	0.03	0.04	0.06	0.07	0.05
U_{cr} [%]	$\bar{x}$	77.34	70.43	70.55	79.39	73.09	71.98	71.00	77.08	76.07
	σ	2.28	0.76	0.69	3.42	1.20	0.39	0.53	3.25	0.37
T_S [°C]	$\bar{x}$	37.98	38.59	38.87	37.15	38.25	37.89	38.05	38.91	38.08
	σ	0.08	0.19	0.15	4.84	0.12	0.38	0.26	0.14	0.14
U_S [%]	$\bar{x}$	19.48	19.13	18.57	20.36	19.13	19.20	18.84	18.84	19.64
	σ	0.11	0.08	0.07	0.53	0.10	0.33	0.05	0.21	0.15
T_G [°C]	$\bar{x}$	20.90	21.48	21.20	20.18	21.44	20.95	21.52	21.17	22.93
	σ	0.09	0.15	0.07	0.08	0.09	0.05	0.09	0.14	0.08
$\dot{V}_{ren}$	$\bar{x}$	130.34	127.65	130.34	127.60	127.72	131.09	128.70	130.74	128.82
	σ	0.82	1.08	1.53	1.46	2.04	1.58	1.36	2.21	2.41

Table 3: Average values and standard deviation of measured parameters at 50 % airflow speed.

		1a	1b	1c	2a	2b	2c	3a	3b	3c
T_{CTR} [°C]	$\bar{x}$	22.36	23.61	23.79	23.55	23.62	24.46	23.34	22.85	23.38
	σ	0.14	0.10	0.05	0.08	0.12	0.05	0.06	0.09	0.14
U_{CTR} [%]	$\bar{x}$	62.78	70.56	68.92	68.86	72.11	68.21	70.63	70.37	69.91
	σ	0.32	0.70	0.41	0.69	0.93	0.32	1.49	0.52	1.04
T_{cr} [°C]	$\bar{x}$	21.70	22.92	23.05	22.89	22.93	23.73	22.71	22.43	22.72
	σ	0.11	0.04	0.05	0.03	0.09	0.05	0.08	0.05	0.10
U_{cr} [%]	$\bar{x}$	65.20	72.31	71.48	71.94	75.10	72.35	71.09	72.43	74.07
	σ	0.40	1.04	0.11	1.56	1.36	0.69	1.80	0.49	1.80
T_S [°C]	$\bar{x}$	31.97	32.90	33.98	31.93	32.50	33.49	32.41	31.97	33.35
	σ	0.09	0.25	0.80	0.21	0.12	0.62	0.15	0.09	0.30
U_S [%]	$\bar{x}$	21.62	22.67	21.79	24.67	22.71	21.36	24.32	23.65	21.73
	σ	0.12	0.20	0.98	0.38	0.26	0.24	0.14	0.10	0.31
T_G [°C]	$\bar{x}$	21.98	21.95	22.27	21.90	22.27	22.75	21.64	20.75	21.76
	σ	0.14	0.33	0.03	0.14	0.54	0.04	0.17	0.19	0.30
$\dot{V}_{ren}$	$\bar{x}$	223.98	231.93	222.30	230.25	233.10	229.05	230.62	229.05	234.58
	σ	1.66	3.54	9.15	1.45	3.18	2.92	2.69	3.41	2.76

Table 4: Average values and standard deviation of measured parameters at 80 % airflow speed.

		1a	1b	1c	2a	2b	2c	3a	3b	3c
T_{CTR} [°C]	$\bar{x}$	21.90	22.01	22.07	22.08	21.77	21.83	21.13	21.70	21.85
	σ	0.07	0.08	0.05	0.08	0.08	0.04	0.14	0.14	0.11
U_{CTR} [%]	$\bar{x}$	69.09	71.19	70.62	69.91	67.67	68.12	62.63	63.48	65.99
	σ	0.26	0.29	2.19	0.81	0.59	0.51	0.64	0.73	0.63
T_{cr} [°C]	$\bar{x}$	21.81	21.90	21.66	21.93	21.43	21.40	20.32	21.03	21.46
	σ	0.03	0.08	0.05	0.05	0.05	0.07	0.10	0.06	0.05
U_{cr} [%]	$\bar{x}$	70.50	71.89	72.32	71.52	70.19	71.14	67.12	67.15	67.62
	σ	0.07	0.40	1.69	0.63	0.65	0.74	0.32	0.30	0.32
T_S [°C]	$\bar{x}$	29.68	29.96	29.14	29.36	29.06	28.87	28.57	29.03	28.68
	σ	0.74	0.45	0.30	0.10	0.23	0.21	0.06	0.35	0.07
U_S [%]	$\bar{x}$	28.32	27.56	27.96	27.87	28.03	28.37	27.35	27.82	28.94
	σ	0.36	0.16	0.16	0.09	0.15	0.24	0.24	0.41	0.16
T_G [°C]	$\bar{x}$	20.19	20.65	20.41	21.03	20.39	19.81	20.70	20.25	20.33
	σ	0.07	0.19	0.12	0.30	0.20	0.18	0.07	0.14	0.10
$\dot{V}_{ren}$	$\bar{x}$	392.87	391.67	392.46	391.11	394.24	394.10	388.96	394.01	386.98
	σ	15.12	6.09	3.98	2.97	4.15	2.99	2.67	6.16	4.80

Tables 2, 3 and 4 show the main microclimatic parameters acquired at 30 %, 50 %, and 80 % of fan speed, respectively. In addition, to the renewal air $\dot{V}_{ren}$, it was also acquired the air conditions of the supply air (T_s and U_s), near the crop (T_{cr} and U_{cr}), and in the middle of the environment (T_{CTR} and U_{CTR}). To complete the characterization of the indoor microclimate it was also acquired the radiant temperature of globe thermometer (T_G).

When the fan speed was set to 30 % and the mean renewal air flow $\dot{V}_{ren}$ was 129.28 m^3/h (Table 2), the spatial mean of crop temperature T_{cr} in the environment was 24.03 °C and the spatial mean of crop relative humidity U_{cr} was 74.10 % with a mean supply air temperature T_s of 38.20 °C. Increasing fan speed to 50 % the mean $\dot{V}_{ren}$ increased to 229.43 m^3/h (Table 3). In this configuration, there was a decrease of mean T_s to 32.72 °C with a consequent decrease of the mean T_{cr} to 22.79 °C. The U_{cr} reached a mean value of 71.77 %. Similarly, with the fan speed at 80 % (Table 4) ($\dot{V}_{ren}$ increased at 391.82 m^3/h), the mean supply temperature dropped further to (T_s 29.15 °C,) and T_{cr} fell to 21.44 °C. In these conditions, the mean U_{cr} is 69.94 %.

To well understand if this environment is suitable for growing of plants like lettuce, it is also important to take into account the influence of temperature by thermal radiation. To determine this effect, it was measured the globe thermometric temperature T_G, that is the temperature measured by Vernon globe thermometer. Varying the air flow rate, the spatial mean of T_G was 21.31 °C, 21.92 °C, and 20.43 °C for 30 %, 50 % and 80 % airflow rate, respectively. Comparing this variation with that of T_{cr}, it was clear that thermal radiation and air flow rates had great effects on plants local temperature. Simultaneously with these measurements, a room temperature T_{CTR} was acquired, with a temperature probe placed on a central pedestal in the room, to have a term of comparison for each acquisition.

As already stated by La Fianza et. al, 2019, the use of the perforated duct in such could permit an optimal plant growing values of the environment properties. At fan speed of 30 % it is possible to note that the mean crop temperature was about 3.0 °C above the set point temperature. This was mainly due to a too low air flow rate. In fact, with a decrease in the air flowrate, the supply temperature must be increased, leading to a higher indoor temperature. To better explain this fact, it is worth remembering that the probe to measure the recovery temperature is installed on the recovery side of the handling unit (Figure 1), which has a value of 21 °C ± 1 °C in each test. At fan speed of 50 % the temperature difference between the crop and set point it was on average 1.8 °C, and at 80 % of about 1.4 °C. This means that the higher speed of fan, which ensures about 10 1/h number of air exchanges, allowed to obtain the best temperature control.

Regarding relative humidity, it can be noted that at fan speed of 30 % the higher values were measured along the diagonal, moving from the humidifier towards the return grid. The same behavior is observed at 50 %, while a more uniform distribution is ensured at 80 %. This means that by setting the fan speed at 80 % is possible obtain a good mixing of the water vapor inside the environment.

In all test, the mean air speed near the crop, in each position is about 0.1 m/s, which is a very good value to prevent transpiration stress of the plants. Although these only represent preliminary results, the knowledge of the indoor distribution of the main microclimatic parameters represent an important aid to better understand how to handle the conditioning systems in the presence of the crops.

4. Conclusion

Microclimatic parameters characterization in confined agriculture environment (CEA) is becoming the most suitable solution to improve technologies able to solve issues related to increasingly urbanization and climate changes. To further enhance their development, it is essential to improve the microclimatic control.

Tests were carried out in a controlled agricultural environment fixing the temperature set point at 21 ± 1 °C and relative humidity at 70 ± 5 % (suitable for lettuce cropping). Their control happened through a handling unit, which supplied treated air by means a perforated duct, and a humidifier. The main microclimatic parameter were acquired by means of microclimatic station equipped with probes and positioning it according to a uniform grid in the environment, for different speed of handling unit fan.

The main results shown that in all tests, the controlled environment is characterised by a good spatial uniformity of parameters value that ensure the equal conditions to all the plants independently by their position. However, the best conditions were observed at 80 % of fan speed, which correspond to about 10 1/h number of air exchanges. This is due to a higher turbulence with a consequent well mixing of water vapor and uniform temperature distribution. The higher the speed does not seem to affect the air speed near the crop, which is 0.1 m/s in all cases, confirming the correct sizing of the air handling unit.

Also the use of perforated duct is confirmed to be an efficient way to spatially uniform the microclimatic parameter distribution inside a confined agriculture environment.

In conclusion, this system can be employed to ensure a more efficient and fast lettuce cultivation thanks to its reliable environment microclimatic control.

References

Abdullah, A., Al Enazi, S., Damaj, I., 2016, AgriSys: A smart and ubiquitous controlled-environment agriculture system. In 2016 3rd MEC International Conference on Big Data and Smart City (ICBDSC) (pp. 1-6). IEEE.

Amitrano, C., Arena, C., Rouphael, Y., De Pascale, S., and De Micco, V., 2019, Vapour pressure deficit: The hidden driver behind plant morphofunctional traits in controlled environments. Ann. Appl. Biol. 175, 313–325.

Fedoroff, N. V., 2015, Food in a future of 10 billion. Agriculture & Food Security, 4(1), 1-10.

Goto, E., 2012, Plant production in a closed plant factory with artificial lighting. VII International Symposium on Light in Horticultural Systems 956, 37-49.

Heuvelink, E., and González-Real, M.M., 2008, Innovation in plant-greenhouse interactions and crop management. Acta Horticulturae, pp. 63–74.

Jensen M.H., 2001, Controlled environment agriculture in deserts, tropics and temperate regions - A world review. In International Symposium on Design and Environmental Control of Tropical and Subtropical Greenhouses 578, 19–25.

La Fianza, G., Giametta, F., Brunetti, L., Orsino, M., Bianchi, B., Perone, C., Catalano, 2019, Thermo-fluid-dynamic characteristics of confluent jets for distribution of treated air in small environment, MODEL-IT 2019.

Ma, D., Carpenter, N., Maki, H., Rehman, T.U., Tuinstra, M.R., and Jin, J., 2019, Greenhouse environment modeling and simulation for microclimate control. Comput. Electron. Agric. 162, 134–142.

Nellemann, C., Macdevetta, M., Manders, T., Eickhout, B., Svihus, B., Prins, A.G., and Kalterrnborn, B.P., 2009, The Environmental Food Crises: The Environment's Role in Averting Future Food Crises. UNEP/GRIP-Arendal, Arendal, Norway.

Nicholsa, M., 2017, Plant factories - The ultimate in controlled environment agriculture. Acta Hortic. 1176, 17–22.

Orsini, F., Kahane, R., Nono-Womdim, R., Gianquinto, G., 2013, Urban agriculture in the developing world: a review. Agronomy for sustainable development, 33(4), 695-720.

Perone, C., Fucci, F., La Fianza, G., Brunetti, L., Giametta, F., Catalano, P., & Bianchi, B., 2017a, Experimental study of a mechanical ventilation system in a greenhouse. Chemical Engineering Transactions, 58, 811-816.

Perone, C., Catalano, F., Giametta, F., ...Bianchi, B., Ayr, U., 2017b, Study and analysis of a cogeneration system with microturbines in a food farming of dry pasta, Chemical Engineering Transactions, 58, pp. 499–504.

Perone, C., Catalano, P., Giametta, F., Brunetti, L., Bianchi, B., 2020, Controlled Mechanical Ventilation to Reduce Primary Energy Consumption in Air Conditioning of Greenhouses, Lecture Notes in Civil Engineering, 67, pp. 399–407.

Shamshiri, R.R., Kalantari, F., Ting, K.C., Thorp, K.R., Hameed, I.A., Weltzien, C., Ahmad, D., and Shad, Z., 2018, Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. Int. J. Agric. Biol. Eng. 11, 1–22.

Staniškis, J., 2012, Sustainable consumption and production: how to make it possible. Clean Technologies and Environmental Policy, 14(6), 1015-1022.

Wada, T., Fukuda, H., Ogura, T., 2019, Fundamental components and points to consider in the design of a plant factory: an example of OPU new-generation plant factory. Plant Factory Using Artificial Light, 231-241. Elsevier.

Yeh N., and Chung. J., 2009, High-brightness LEDs: Energy Efficient Lighting Sources and Their Potential in Indoor Plant Cultivation. Renewable and Sustainable Energy Reviews 13(8), 2175–2180.