Integrating Hydroponics Into Office Buildings: Impacts Of Plants On The Building Environment And Office Occupants

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Introduction

Almost 4 billion people are living in cities around the world, representing 54% of the global population (UN, 2015), and the built environment accounts for over half global CO_2 emissions. Global urban population is set to rise by 2.6 billion by 2050, which will continue to put pressure on the energy supply of cities. Thermal comfort is the driver behind building energy consumption in developed cities (Yang et al., 2014), and energy used for cooling is expected to rise by up to 30% by 2050 (Kolokotroni et al., 2012).

As cities are increasingly considering green technologies to improve resource use efficiency, this poster presents how hydroponic modules could be used in offices to reduce temperatures and lower CO_2 levels, based on a programme of monitoring and simulation.

First, the setup and design of 50 hydroponic modules in the James Dyson Building (JDB) in Cambridge, UK, will be presented, before showing how qualitative and quantitative data is being captured to monitor the impacts of plants on the building and occupants. The second section introduces a method to combine a plant-air interaction model ("plant module") into building energy simulation model. Initial results of modelling the third floor of the JDB by integrating the plant module into TRNSYS will show the potential of simulating plants in buildings.

Implementing hydroponics into an office building

Setup of hydroponic systems

Hydroponic systems offer an efficient method for intensively growing plants in controlled environments, with plant roots suspended in nutrient rich water, with minimal inputs of resources compared to conventional methods (Kozai, 2016). Two systems were installed in the building: 45 hydroponic modules from IKEA (Tragger/Vaxer, Figure 1) on windowsills by the glass facades and on desks, and 4 Aponic vertical aeroponic modules along building columns and in the communal area (Figure 2). In total at the time of writing, there were 280 plants growing, and their location is illustrated on the third floor of the JDB in Figure 3. Opened in 2016, this new building was amenable to input of hydroponic modules and the open plan layout is representative of the commercial building stock in the UK.

Figure 1: IKEA module with white cabbage

Figure 2: Aponic unit with basil

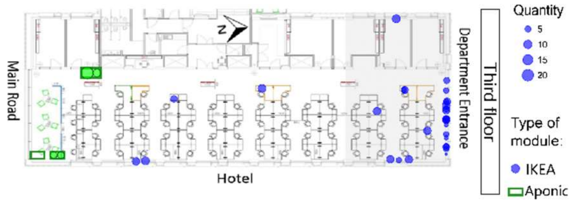

Figure 3: Third floor layout of JDB with plant module location

Monitoring environmental conditions and occupants

Sensors spaced at regular intervals monitor temperature, CO_2, and ventilation patterns in the office. The JDB's high occupancy rates lead to high CO_2 levels (over 600 ppm for over 6 hours of the workday on average) and ambient conditions (20-25°C, 50-80% humidity) which are ideal for productive plant growth (Kozai et al., 2016). Furthermore, qualitative data on plant growth, and on the impact of plants on occupants, in terms of perceived quality of space, food production, office community and knowledge of plants growth was regularly collected. Initial feedback will be presented in the poster.

Simulation of plants in buildings

Theory of plant-air interaction

Plant growth leads to CO_2 and heat exchange with the environment. Modelling so far has been limited towards horticultural commercial sites or building-integrated greenhouses. The plant-air interaction is schematically illustrated by Figure 4 where the heat and gas exchanges are detailed at plant level. The impact of plants growing inside the building can be modelled through considering the following exchanges (illustrated schematically in Figure 5):

(1) *Sensible heat*: exchange of heat, measured by temperature, between the layers in the plant module, and the plant module and surrounding environment, due to convection, conduction and radiation processes.

(2) *Mass and latent heat*: water vapour exchange due to temperature differential between different components, and mostly due to plant transpiration. Air and stomatal resistances are the dominant factors influencing transpiration rates.

(3) *CO_2 and O_2*: throughout the plant photosynthesis process, the plant exchanges gases with the environment for their growth and maintenance. Further details of the equations used and parameters for an indoor plant module will be described in the poster.

Integrating a model into TRNSYS

A model of the JDB has been created using the building energy simulation software TRNSYS. Since building

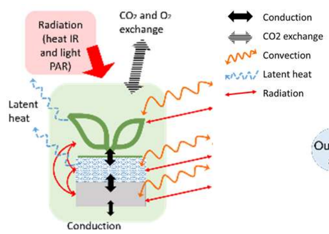

Figure 4: Schematic of heat transfer process at plant level.

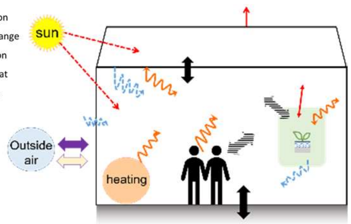

Figure 5: Integration of plant module into building energy model.

energy simulation models currently do not include plants, a MATLAB plant model developed for the Growing Underground farm (Ward et al. 2017) was adapted by Gillard (2018) and incorporated into the TRNSYS model. This allows the impact of the plants on the internal air quality of the building to be explored.

Model results

Integrating the plant module into the building energy simulation allowed the modelling of CO_2 change with planted area for comparison against data monitored over a year. The integrated plant model resulted in reducing CO_2 levels as planted area increases, compared to the monitored data. Furthermore, Figure 6 shows that temperatures decrease as the planted area increases, by 10% for a planted area of 100 m^2 (representing a quarter of the floor surface area). Not shown here, but a parallel increase in humidity was observed. Table 1 shows how energy use for heating decreases as the planted area increases, as output from TRNSYS.

Further monitoring of the CO2, temperature and humidity in the office in areas with and without plants will be used to calibrate the parameters in both the plant module and in the TRNSYS building energy simulation.

Conclusions

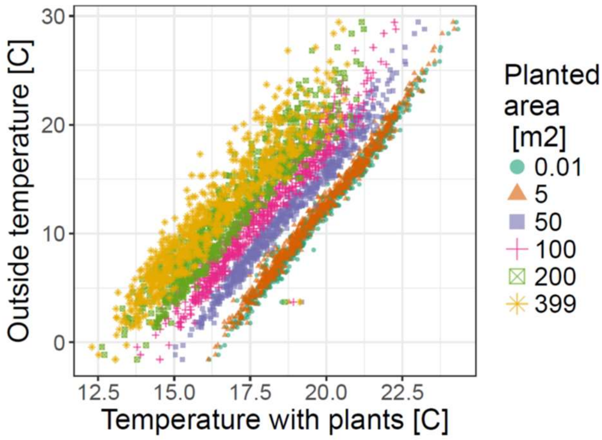

Figure 6: Temperature modelled with the plant module and TRNSYS, as a function of outside temperature, for different planted areas (m^2).

The aim was to provide a basis for modelling the impact of adding plants to a conventional office on temperature, humidity and CO_2 concentration, using typical building energy simulation software. The first attempt presented in the poster shows promising results. Future work will improve the parameterisation of the model and will aim to validate the results against monitored internal conditions and published data of CO_2 assimilation rate of edible plants. Furthermore, qualitative surveying and monitored data allows for a holistic view of the impacts of plants and will influence future developments of the simulation and monitoring approach.

Table 1: Annual energy use for heating in MWh for heating per planted area. Current planted area is 40 m2.

0 m^2	40 m^2	100 m^2	200 m^2	400 m^2
32.3	31.9	31.0	30.1	28.9

Acknowledgements

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