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Assessing, Benchmarking and Analyzing Heating and Cooling Requirements for Glasshouse Food Production: A Design and Operation Modelling Framework

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Abstract

Growing populations, increase in food demand, society's expectations for out of season products and the dependency of the food system on fossil fuels stress resources due to the requirements for national production and from importation of products from remote origins. Quantifying the use of resources in food production and their environmental impacts is key to identifying distinctive measures which can develop pathways towards low carbon food systems. In this paper, a modelling approach is presented which can quantify the energy requirements of heated glasshouse food production. Based on the outputs from the model, benchmarking and comparison among different glasshouse types and growers is possible. Additionally, the effect of spatial and annual weather trends on the heating and cooling requirements of glasshouses are quantified. Case study results indicate that a reduction in heating requirements of about 50%, and therefore an equivalent carbon footprint reduction, can be achieved by replacing a single glass sealed cover with a double glass sealed cover.

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Keywords: Glasshouse; Heated production; Protected production; Glasshouse operation and design; Glasshouse energy requirements

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Nomenclature

A	area, m^2
c_p	specific heat at constant pressure, kJ kg^{-1} K^{-1}
D	distance, m
e	vapour pressure, kPa
$\dot{E}$	electrical power, kW
F	flow rate, m^3 s^{-1} m^{-2}
h_{fg}	latent heat of vaporization, kJ kg^{-1}
I	solar radiation, kW m^2
N	infiltration rate, s^{-1}
p	pressure, kPa
$\dot{Q}$	heat transfer rate, kW
r	radius, m
R	gas constant
SFP	specific fan power, kW m^{-3} s^{-1}
t	time
T	temperature, K
U	overall heat transfer coefficient, kW m^{-2} K^{-1}
v	specific volume, m^3 kg^{-1}
V	volume, m^{-3}
W	humidity ratio, kg_{vap}/kg_{air}
Greek letters	
β	absorbed radiation ratio
η	efficiency
θ	latitude, rad
ρ	density, kg m^{-3}
φ	longitude, rad
Subscripts	
a	actual
b	boiler
c	cover
f	floor
i	in
o	out
p	pressure
s	time step
v	vapour

1. Introduction

It is projected that global food production will increase by 70% by 2050 as a result of population increase [1]. Consequently, huge pressure at all stages and processes of food supply chains is expected to be applied in the attempt to satisfy this growth in demand and resources requirements. This will almost certainly lead to increase in energy consumption and carbon footprint but also create a feedback effect that can further deteriorate the situation. Given that the UK food sector is highly dependent on fossil fuels and there are ambitious targets in reducing carbon emissions [2], it is important to find methods for minimizing the energy requirements and carbon intensity of such activities. Considering the fact that based on estimations from published figures by Refs. [3,4], the UK domestic food sector