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Numerical investigation of the energy performance of an Opaque Ventilated Façade system employing a smart modular heat recovery unit and a latent heat thermal energy system

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HIGHLIGHTS

- An innovative E2VENT ventilated façade system is presented and modelled with TRNSYS.
- The energy efficiency of the system is assessed for five climates in Europe.
- The E2VENT retrofitting system is compared with a traditional retrofit method.
- The E2VENT system achieves 16.5–23.5% primary energy saving.
- The E2VENT system saves twice as much primary energy as the traditional retrofit.

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ABSTRACT

The building sector is responsible for more than 40% of the EU's total energy consumption. To reduce the energy consumption in buildings and to achieve the EU's fossil fuel saving targets for 2020 and beyond 2050, the energy efficient retrofitting strategies are critically important and need to be implemented effectively. This paper presents a dynamic numerical investigation of the energy performance of an innovative façade integrate-able energy efficient ventilation system (E2VENT) that incorporates a smart modular heat recovery unit (SMHRU) and a latent heat thermal energy system (LHTES). A number of component simulation models, including SMHRU, LHTES, Cladding and Building Energy Management System (BEMS), were developed and then integrated using the TRNSYS software which is an advanced building energy performance simulation tool. On this basis, sizing, optimisation and characterisation of the system elements including the HVAC system and insulation layer thickness were carried out. The overall energy efficiency of the E2VENT system and its impact on the energy performance of a post-retrofit building were then investigated. In particular, the heating and cooling energy performance of the E2VENT façade module was numerically studied at five different climatic conditions in Europe. Furthermore, the innovative E2VENT retrofitting was compared with traditional retrofittings in terms of the energy efficiency and primary energy savings. It was found that the innovative E2VENT solution can achieve 16.5–23.5% building primary energy saving and compared to the traditional retrofitting, the E2VENT solution can achieve two times less primary energy consumption. Thanks to this efficiency the development of this solution for buildings retrofit is promising.

1. Introduction

Façade renovation is recognised as one of the most efficient strategies in reducing energy consumption in buildings. The ventilated façade, as one of the best solutions in managing the interaction between the outdoor and indoor environments [1], is

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Nomenclature

A	Area, m^2
Cp	thermal capacity, J/kg/°C
COP	coefficient of performance, –
D	diameter, m
dt	time step, s
E	energy consumption, kW h
Fa	staggered arrangement
d_{out}	tube outside diameter, m
d_{in}	tube inside diameter, m
b	constant
c	constant
h	heat transfer coefficient, W/K
H	heat loss, °C/W
L	PCM latent heat of fusion/solidification, J/kg
l	length, m
marge	static pressure loss marge, –
NTU	Number Transfer Unit
Nu	Nusselt, –
NX	number of tubes'rows, –
NY	number of tubes per row, –
P	power, W
Phl	average heat losses, W
Pr	Pranlt number, –
PX	longitudinal pitch between two rows, m
PY	transversal pitch between two tubes, m
q	air volume flow rate, m^3/h
Q	heat transfer rate, W
$Q_{exhaust}$	the exhaust air of the SMHRU, W
Q_(surf,i)	the convective gain from surfaces
Q_(inf,i)	is the infiltration gains, W
Q_(vent,i)	is the ventilation gains, W
Q_(g,c,i)	convective gains (by people, equipment, illumination, etc.)
Q_(cplg,i)	gain due to (connective) air flow from air node or boundary condition, W
Q_(ISHCCI,i),	the absorbed solar radiation on all internal shading devices, W
Q_{supply}	supply mass flux air, W
Re	Reynolds
Rhl	heat losses resistance, W
t	time, s
T	temperature, °C
ΔT	temperature range of fusion/solidification, °C
ΔT_f	PCM temperature range of fusion/solidification, °C
v	velocity, m/s
X	heat exchanger height, m
Y	heat exchanger depth, m
Z	heat exchanger width, m

Subscripts

a	air
ad	air duct
ave	average
cond	conduction
conv	convection
ext	external
elec	electricity
int	internal
f	fusion
fan	fan
mec	mechanical
i	node
in	inside, indoor
m, pcm	for phase change material (PCM)
p	primary energy
s	cross section
t	tube
out	outside, outdoor
PCM	Phase Change Material

Greek

Δ	difference between two states
ε	efficiency
λ	conductivity
μ	dynamic viscosity, Pa s
ρ	density, kg/m^3
w	absolute humidity

getting the growing popularity owing to its effectiveness in energy saving, simplicity in implementation and relatively low cost. In recent years, several studies were undertaken on various ventilated facade types including Double Skin façades [2], integrated PV façades [3–5], façade solar collectors [6], Solar chimney and Trombe walls [7–9], etc. However, studies on Opaque Ventilated Façades (OVFs) have not yet been reported, possibly owing to their limited application (i.e., residential buildings only) [10]. An Opaque Ventilated Façade comprises three layers: an inner building envelope, an air cavity (ventilated naturally or mechanically) and an opaque external skin. Several experimental and numerical studies were undertaken in order to characterize the main factors affecting the thermal performance of these systems and their capacity to reduce heating and cooling loads. López and Santiago [11] carried out a numerical sensitivity study that is to address the efficiency of an OVF in winter for different climatic zones in Spain, indicating that the ventilated façade is best suited to the low winter severity climate. Further, solar radiation was found to be the most relating variable to energy efficiency of the façade, while the combination of high temperature and low wind speeds could lead to significant energy saving of the façade. López et al. [12], by using TRNSYS, simulated an experimental OVF module, indicating that the Opaque Ventilated Façade has potential to achieve free ventilation and air preheating and its performance could largely be dependent on the wind speed and direction, as well as the intensity of solar radiation. Aparicio-Fernández et al. [13] made the combined use of TRNSYS and TRNFlow to simulate the performance of an OVF, and compare the simulation results with experimental data. The study indicated that the collection of the hot air from the façade for the use in the building helped to reduce the building's heat demand. Some authors [14–18] conducted the numerical investigation of the performance of the OVF by comparing it with the same sized unventilated façade (without the air cavity) or sealed façade. The results show that the OVF can achieve more than 40% energy saving during summer period owing to the reduction in heat gain and ventilation of the air cavity. During winter, some results [16–18] show that the OVF is less advantageous mostly for low solar radiation period. In fact, when solar radiation is low, the cold air will be sucked into the cavity that will lead to the increased heat losses. However, when solar radiation is higher, the hot air will be gathered at the air cavity that leads to the reduced pressure difference between the inside and outside of the building; consequently, the heat loss of the building will be significantly reduced.

In order to improve the efficiency of OVFs, some PCM materials were attached to the external skin of the OVF while some