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Buildings dynamic simulation: Water loop heat pump systems analysis for European climates

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ABSTRACT

In this paper, a purposely designed code for the performance analysis of the Water Loop Heat Pump (WLHP) systems is presented. Hourly, daily and seasonal energy system consumptions, operating economic costs and environmental impact assessments are dealt with. For the scope of comparison, the performances of two reference HVAC system are investigated too. For the computation of the building heating and cooling requirements, a suitable dynamic performance simulation model is being developed. All the relevant algorithms are implemented in MATLAB®. A case study of an office building undergoing simulation in different European climatic areas is being presented. Here, different building thermal features are considered. In order to maximize the system performance an additional optimization procedure to the operating devices temperatures is carried out. Results show that primary energy savings and avoided CO_2 emissions of the WLHP system vary in relation to the compared reference systems and can be obtained only in several European weather zones. The feasibility of the WLHP system strongly depends on electricity and natural gas national costs.

1. Introduction

In buildings where space heating and cooling loads simultaneously occur, a Water Loop Heat Pump (WLHP) system can be conveniently adopted [1,2]. Basically, it consists of a set of heat pumps that reject to a water loop the excess heat from cooled space. Such heat is recovered by other heat pumps and transferred to spaces in need of heating. In the water loop, the occurring heating or cooling deficits are balanced by additional heaters and/or cooling towers. WLHP systems are typically installed in edifices with distinguished core and perimeter zones or commercial building with deep freeze or cold stores. A basic scheme of a WLHP system is reported in Fig. 1.

Such systems were developed in the 1960s in USA, they became widely popular and applicable since 1990s mostly in USA and Japan. In recent years, several studies were carried out aiming at evaluating the system component features and relative operating parameters. An investigation concerning the WLHP system's environmental contribution to a green building environmental control is reported in [3]. In this study, alternative options to increase the building's energy performance were considered. A comparison between conventional air-conditioning systems and a WLHP system for a number of Chinese climatic zones is carried out in [4]. An interesting analysis of the WLHP performances on four different kinds of buildings was presented, where the devices' efficiencies of the simulation model are kept constant [4]. In order to increase the system energy saving, other authors studied the combination of WLHP systems with gas-engine-driven heat pump (GHP) [5] and coupled with low-temperature geothermal sources [6,7]. In particular in [6] the evaluation of system performance and energy saving for commercial and public buildings is carried out. The efficiencies of the water source heat pumps are considered dependent on the loop water temperature that ranges between 16 and 32 °C. A constant cooling load profile is adopted for the core building zone. For the perimeter zone, the heating load is assumed linear to outdoor temperatures. In [7] WLHP system is applied to three tower-shaped apartment building in Beijing (China) where well water is used as the low-temperature heat-source. The system performances are analyzed using a field-test data obtained by running the system over two winters and a summer. The system controlling conditions are also investigated. In [8] a given test building load profile and a single type of WLHPs equipped with a variable speed compressor and a cooling tower with a variable speed fan are considered in order to find out the optimal loop water temperature minimizing the WLHP overall energy consumption.

In this paper, a detailed, purposely-designed performance simulation model for the building-WLHP system is presented. Its computer implementation, obtained by MATLAB®, allows assessing hourly, daily and seasonal building-HVAC system performances, from an energy, economic and environmental points of view. This tool allows the variation of system running parameters in contrast

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Nomenclature

C	economic cost (€)
b	capacitance (J/K)
c	specific heat (kJ/kg K)
ce	electricity unitary cost (€/kW h)
cg	natural gas unitary cost (€/N m^3)
E	primary energy consumption (MW h/y)
G	Gebhart matrix for long wave radiation (–)
H	hour
h	specific enthalpy of the moist air (kJ/kg)
K	solar radiation (W/m^2)
I	solar flux intensity (W/m^2)
$\dot{L}$	electricity rating (kW)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat load (kW)
Q	heat (kW h)
r	resistance (K/W)
R	saving
S	surface (m^2)
t	time (s)
T	temperature (°C)
$THVAC$	traditional HVAC
U	thermal transmittance (W/m^2 K)
Z	building thermal zones

Greek letters

α	absorptance (–)
Γ	long wave internal radiation (W)
Φ	external radiation (W)
Ψ	short wave internal radiation (W)
ε	long wave radiation emissivity (–)
η	efficiency (–)
θ	running hourly ratio (–)
λ	conductivity (W/m K)
ρ	density (kg/m^3)
τ	optical transmissivity (–)
σ	Stefan–Boltzmann constant (W/m^2 K)

Subscripts

A	air
AW	air to water electric chiller and traditional natural gas boiler
B	boiler
bal	balance
C	compressor
Co	condenser
$Cool$	cooling mode
CT	cooling tower
db	dry bulb
Ev	evaporator
e	electric
ext	external surface
g	natural gas
$Heat$	heating mode
$HVAC$	referred to the HVAC system
in	indoor
int	internal surface
o	outdoor
TB	traditional system boiler
TOT	total
V	ventilation
w	water
$WLHP$	water loop heat pump
WW	water to water electric chiller and traditional natural gas boiler
wb	wet bulb
y	year

Superscripts

$'$	entering the WLHPs
$*$	exiting the boiler
e	economic
H	heating mode only
S	load simultaneity
C	cooling mode only

to other available commercial software which do not allow several system configuration to be stimulated. A comparison of the WLHP system performance vs. the Traditional HVAC (THVAC) systems is also carried out. The devices-efficiencies are variable in relation to the systems operating conditions and an optimization procedure on the water loop temperatures to maximize the systems performance is also implemented. A case study relative to large office buildings is finally presented. Simulations correlate to a number of European climatic zones. Both existing building and new construction components features are selected according to the outdoor climate. The performance analysis of the WLHP system for different European climates and kinds of buildings is novel with respect to what is published in the recent literature. A primary and basic simulation model in addition to some partial results about the system performance are presented in [9,10].

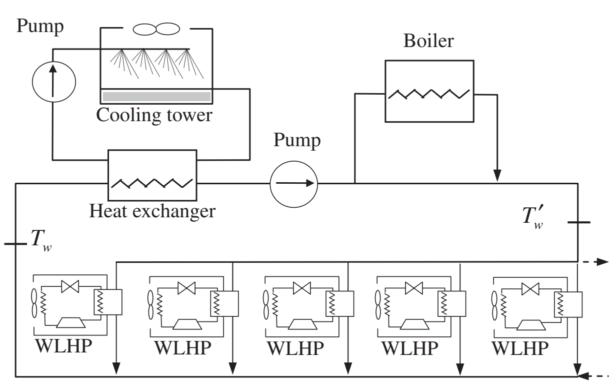

Fig. 1. Basic scheme of a WLHP system.

2. Modelling

In recent years, several numerical simulation models for the building-HVAC system performance evaluation were developed [11–14]. In general, such simulation tools can be categorized with respect to the tasks they are meant to fulfil (equipment sizing and selections, energy performance analysis, system optimization, control analysis, etc.). Although the current generation tools tend to be fully integrated with respect to different building performance aspects, the integration between building and HVAC system models is accomplished at different levels. However, for comparing HVAC system alternatives and evaluating different control strategies, detailed HVAC system models are required [15]. In this paper, in order to well quantify the effects of the input parameters to the output results of a numerical simulation study, a purposely designed building-HVAC dynamic simulation model was developed.