Energy 74 (2014) 762–774

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Assessment regarding energy saving and decoupling for different AHU (air handling unit) and control strategies in the hot-humid climatic region of Iraq

Raad Z. Homod*

Department of Petroleum and Gas Engineering, University of Basrah, Qarmat Ali Campus, 61004 Basrah, Iraq

ARTICLE INFO

Article history:
Received 31 January 2014
Received in revised form
9 July 2014
Accepted 16 July 2014
Available online 12 August 2014

Keywords:
Decoupling HVAC system
Improving control performance
PMV model
HVAC energy efficiency
Optimal thermal comfort

ABSTRACT

In a hot and humid climate, HVAC (heating, ventilating and air conditioning) systems go through rigorous coupling procedures as a result of indoor conditions, which are significantly affected by the outdoor environment. Hence, a traditional method for addressing a coupling setback in HVAC systems is to add a reheating coil. However, this technique consumes a significant amount of energy. Three different strategies are designed in a hot and humid climate region, such as Basra, for AHUs (air handling unit), and their evaluations of decoupling are compared. The first and second strategies use the same feedback control references (temperature and relative humidity), except the second one also uses a reheating coil and a wet main cooling coil. The AHU (air handling unit) of the third (proposed) strategy is equipped with a dry main cooling coil and a wet pre-cooling coil to dehumidify fresh air, which allows the controller to handle the coupling problem. Furthermore, the proposed strategy utilises the PMV (predicted mean vote) index as a feedback control reference to increase optimisation parameters that provide more flexibility in meeting the thermal comfort sensation. The adaptive control algorithm of nonlinear multivariable systems is adopted to coordinate these three policies of optimisation. The results of the three strategies show that the proposed scheme achieved the desired thermal comfort, superior performance, adaptation, robustness and implementation without using a reheating coil.

1. Introduction

In recent decades, studies on the parameters of HVAC (heating, ventilating and air conditioning) systems, such as the temperature, PMV (predicted mean vote), HVAC system structure volume and control strategies, have demonstrated high performance in HVAC systems, particularly in regard to saving energy [1]. Temperature is commonly used as the thermal comfort control objective in early HVAC systems [2,3]. However, temperature alone does not ensure a person's thermal comfort [4]. Temperature and relative humidity are coupled; hence, it is difficult to control both factors when each has its own strict set point [5]. But, the demands for modern HVAC systems regarding highly systematic products, material integration and energy integration have resulted in strictly coupled processes. This coupling has exposed many of the uninvited characteristics of HVAC systems, which are reflected in the limitations of the classical controllers, such as PID (Proportional Integral Derivative), that are used to manipulate the AHU (air handling unit) inputs. Furthermore, the currently used PID tuning techniques are inadequate when dealing with MIMO (multi-input, multi-output) processes [6,7]. PI (Proportional Integral) and PID controllers are commonly used in HVAC systems due to their simplicity in structure and their relative effectiveness; additionally, the units can be easily understood, which makes them practical to implement [8].

Usually, the decoupling method is adopted to release or alleviate the coupling of two or more of the control objectives in two or more of the interlaced loops, which is a difficult task for most of the plant model because all of the decoupling techniques have limitations [9,10]. The conventional solution includes adding a reheating coil to address this coupling setback. However, the use of a reheating coil increases the power consumption through the control of the RH (relative humidity) in the conditioned space when the thermal comfort is maintained at an acceptable level [11,12]. Generally, two types of decoupling control systems are currently used: static and dynamic. Static decouplers are effective when high response controls are not required to oversee the processes [13]. Additionally, the design of static decouplers is straightforward, and their implementation is based on the inverse process of steady state

---

* Tel.: +964 7821731696; fax: +964 60 389212116.
E-mail addresses: raadahmood@yahoo.com, raad.homod@uobasrah.edu.iq.

http://dx.doi.org/10.1016/j.energy.2014.07.047
0360-5442/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

Symbols

A	surface area, m^2
C	heat capacitance, J/°C
dE_s/dt	rate of change in storage energy of the system, J/s
$\dot{E}_{in}$	energy rate entering the system, J/s
$\dot{E}_{out}$	energy rate leaving the system, J/s
M	mass, kg
Cp	specific heat, J/kg°C
$\dot{m}$	mass flow rate, kg/s
Mcp	heat capacitance, J/°C
T	temperature, Co
ω	humidity ratio, kg$_w$/kg$_{da}$
h	latent heat/heat transfer coefficient, J/kg, W/(m^2°C)
$\dot{Q}$	cooling load, *W*C
CF	surface cooling factor, W/m^2
U	construction U-factor, W/(m^2°C)
ΔT	cooling design temperature difference, °C
OF_t, OF_b, OF_r	opaque-surface cooling factors
DR	cooling daily range, °C
CF_{fen}	surface cooling factor, W/m^2
U_{NFRC}	fenestration U-factor, W/(m^2°C)
PXI	peak exterior irradiance, W/m^2
SHGC	solar heat gain coefficient
IAC	interior shading attenuation coefficient
FF_s	fenestration solar load factor
E_t, E_b, ED	peak total, diffuse, and direct irradiance, W/m^2
T_x	transmission of the exterior attachment
F_{shd}	fraction of the fenestration shaded by overhangs or fins
L	site latitude, °N
SLF	shade line factor
D_{oh}	depth of the overhang, m
X_{oh}	vertical distance from the top of the fenestration to the overhang, m
F_{cl}	shade fraction closed (0–1)
ψ	exposure (surface azimuth), measured as degrees from south
$\dot{V}$	volumetric flow rate, L/s
DF	infiltration driving force, L/(s cm^2)
$\Re$	thermal resistance, °C/*W*
N_{oc}	number of occupants
N_{br}	number of bedrooms
α_{roof}	roof solar absorbance
τ	time constant, s
I	infiltration coefficient
$\Delta\omega$	indoor–outdoor humidity ratio difference, kg$_w$/kg$_{da}$

Subscripts

m	air in mixing box
r	room/return
o	outside
os	outside supply
i	inside
He	heat exchanger
a	air
w	water
aHe	air in the heat exchanger
L	leakage
W_{in}	water input
W_{out}	water output
Wl	wall
room	inside room
out	outside room
g	glass
fg	heat of vaporization
Opq	opaque
inf	infiltration
fen	fenestration
f	indoor and outdoor
t	at time t
flue	flue effective
es	exposed
ul	unit leakage
ig	internal gains
l	latent
s	sensible/supply
fur	furniture
cl	closed

gains. However, static decouplers may not always be able to provide satisfactory control performance. In contrast, dynamic decouplers require detailed process models, but they provide better performance than static decouplers provide [14,15]. For practical operations, the emphasis is typically placed on suitability and causality needs, which makes precise configurations difficult to achieve, especially for high-dimensional MIMO processes. To settle these difficulties, most of these methodologies focus on TITO (two input and two output) systems [16,17]. The main shortcoming of the dynamic methods lies in the complexities of the decoupler elements, which are obtained from the apparent process model. The difficulty becomes greater for sophisticated plants because the technique incorporates the determinant of the model transfer function [18]. Additionally, the requirement for the decoupler is that all of its elements must be proper, causal and stable [19]. A few studies in the literature have focused on the inverted decoupling methods that are used to reduce variable interactions in the process [18–22]. Gagnon [10] demonstrated that the performance of inverted decoupling depends on the scheme of implementation. When inverted, decoupling is implemented with a lead-lag and delay function process, and the control performance retreats. Normalised decoupling control design methodology was used by Shen [23]. For this type of decoupling, the ETF (equivalent transfer function) of each element in the transfer function matrix was required to derive the closed-loop of the plant model, including the algorithm of the control system. Then, the decoupler was obtained by multiplying the inverse of the ETF by a stable, proper and causal ideal-diagonal transfer function.

This paper seeks to analyse and discover the paramount choice of controlled parameters in the HVAC systems, which are reflected in optimisation controller performances. However, the controller's performance is related to buildings' energy efficiency, which is most directly affected by the decoupling problem. Therefore, in this study, the extensive and elaborate models of a building that has HVAC system components are used to simulate a real system. Deriving the matrices of decoupling, inverted decoupling or ETF from such a complex model is challenging because all of its elements must be proper, causal and stable. In concision, the HVAC control systems use both temperature and RH as references instead of using temperature only, which is what the earlier mode did. Because temperature and RH are coupled, it is difficult to control them separately for a certain desired value [11].