Energy and Buildings 103 (2015) 14–28

Contents lists available at ScienceDirect

Energy and Buildings

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

Adaptive predictive control of thermo-active building systems (TABS) based on a multiple regression algorithm

Martin Schmelas*, Thomas Feldmann, Elmar Bollin

Institute of Energy System Technology (INES), Offenburg University of Applied Sciences, Badstrasse 24, 77652 Offenburg, Germany

ARTICLE INFO

Article history:
Received 10 January 2015
Received in revised form 25 May 2015
Accepted 3 June 2015
Available online 10 June 2015

Keywords:
Thermo-activate building system (TABS)
Concrete core activation
Adaptive predictive control
Multiple regression
Thermal comfort

ABSTRACT

There is a growing trend toward the use of thermo-active building systems (TABS) for heating and cooling buildings, since these systems are known to be very economical and efficient. However, due to the large thermal inertia, the control of these systems turns out to be complicated and time-consuming in the parameterization. With standard control strategies, the required thermal comfort in buildings often cannot be met, especially if the internal heat sources are suddenly changed. This paper presents a novel adaptive and predictive computation method, based on multiple linear regression (AMLR) for the control of TABS. Through the self-learning effect, no parameterization of heating and cooling curves is necessary. The algorithm is compared to a conventional control strategy for TABS. In this simulation case, it turns out that the adaptive and predictive control strategy can achieve a saving of pump-running time of up to 81% while increasing thermal comfort. In addition, the algorithm is validated by a three-week laboratory experiment. With simple calculation approaches, this algorithm proves to be very practical and can easily be integrated into a building's automation system. Furthermore, it offers the possibility for load shifts from the use of the thermal mass of a building.

1. Introduction

From 1990 to 2010, the global primary energy demand increased by 50% [1]. The building sector is a major consumer of energy. In the tertiary sector in 2012, the share of final energy consumption in the European Union was at 42.6%, in the industry sector at 25.6%, and in the transport sector at 31.8% [2]. A large part of the tertiary sector accounts to the energy consumption of buildings. Most of this consumption is needed for their heating and cooling. Therefore, heating and cooling concepts which use renewable energy sources become increasingly important. For this purpose, low temperature systems, such as thermo-active building systems (TABS), are particularly suitable. There are different system configurations and designations for TABS [3,4]. However, all system configurations have in common that the pipes are located within the building structure, so that the building can be heated and cooled. A very popular and often used system configuration is known as *concrete core conditioning* and *concrete core activation*.

One of the first buildings to be equipped with concrete core activation was built in Switzerland in 1990/1991 [3]. In 2001, there were a total of more than 60 buildings with TABS in Germany. In 2007, 508 new buildings were equipped with 483,000 m^2 of concrete core activated area [5] in Germany. Reasons for the rapid spread are mainly the increasing trend of better insulation of exterior façades in the course of the German regulation for energy saving in buildings and building systems (EnEV) as well as the many benefits of TABS. They mean comparatively low investment costs for new buildings and high economic efficiency due to the energy efficiency of these systems. Low over- and under-temperatures as well as large heat transfer areas allow for the use of environmental energy (soil, groundwater, ambient air) with the help of heat pumps. Of particular interest to architects is the factor that TABS are not visible because they are placed inside the concrete. By natural convection, there is no high velocity air movement in a room, and therefore the problem of draft effects can be excluded. Due to the possibility of active loading and unloading of the thermal mass of a building, load peaks can also be flattened and loads can be shifted within one day [5]. Because TABS behave like a thermal storage, they have a high potential for load shifting on the basis of external signals [6]. Nevertheless, there are also some disadvantages. These include low heating and cooling powers because the supply temperature is limited due to condensation and discomfort. For example, supply temperatures of at least 16 °C and up to 30 °C are recommendable in office buildings. In addition, the large thermal inertia of these systems does not allow for fast reactions to room temperature changes. For conventional control strategies,

* Corresponding author. Tel.: +49 7812054605.
E-mail address: martin.schmelas@hs-offenburg.de (M. Schmelas).

http://dx.doi.org/10.1016/j.enbuild.2015.06.012
0378-7788/

Nomenclature

A	area [m^2]
C	capacitance [J/K]
φ	density [kg/m^3]
Q	energy [Wh]
$\dot{Q}$	heat flow [W]
U, α	heat transfer coefficient [W/m^2 K]
I	irradiance [W/m^2]
$\dot{m}$	mass flow [kg/h]
l	pipe length [m]
δ	pipe outside diameter [m]
c	specific heat capacity [J/kg K]
$\dot{q}$	specific heat flow [W/m^2]
P	state of pump
T	temperature [°C]
λ	thermal conductivity [W/m K]
R	thermal resistance [m^2 K/W]
d	thickness [m]
τ	time [h]

Indices

add	additional
amb	ambient
b/concr	concrete
ext	external
f	façade
glob	global
hist	historic
int	internal
k	core
m	mean
mc	from supply and return
MLR	multiple linear regression
mr	mean radiant
op	operative
p	pipe
pred	predictive
R	room
R1	room 1
R2	room 2
RW	return water
set	set-point
sp	specific
SW	supply water
t	thermal
TABS	thermo-activate building system
ua	from heat transfer calculation
w	water
wi	window
wl	thermal load
x	*x* direction
z	*z* direction

it can be very difficult to handle this thermal inertia. Predictive controllers have shown to better handle the thermal lag, e.g. [7,8].

This work focuses on the control of TABS and compares conventional control strategies with a novel adaptive and predictive control of TABS, based on a multiple linear regression algorithm. Therefore, the conventional strategies as well as the newly developed control strategy are presented. Annual simulations of TABS operation are evaluated and compared to each other in thermal comfort, energy efficiency and adaptability. In addition, results from a laboratory test with the new algorithm are presented.

2. Conventional control of TABS

In this section, the most frequently used control strategies for heating and cooling with TABS are presented. These strategies are analyzed in more detail in [9–11]. In principle, the mass flow and the supply temperature can be varied to control the loading and unloading of TABS. Typically, the mass flow is constant in conventional strategies. The pump is driven by a binary signal, and thus, the operation time of the pump is varied. The TABS supply temperatures are controlled. Several building areas with identical internal loads are usually summarized as so-called zones. For the hydraulic integration of TABS, there are different variants which are summarized in [12] with their advantages and disadvantages. The following section is focused on control strategies of TABS.

2.1. Three-step control in dependency of the room temperature

The three-step control in dependency of the room temperature is comparatively the simplest method to control TABS. In [13] and [14], this type of control is examined with the aid of experiments. This control strategy does not contain any information about the dynamics of the respective building. The supply temperature of TABS always corresponds to the minimum possible supply temperature in cooling mode and to the maximum supply temperature during heating, respectively. The controlled temperature is the room temperature, which has to be available through a temperature sensor. If it falls below the set-point, the zone pump receives the signal "ON" with the maximum supply temperature. Once the set-point is exceeded, the pump receives the signal "OFF". The cooling is realized on the same principle. In order to try to avoid frequent switching, the three-step control can also be applied with switching hysteresis. In [15] a three-step control strategy with hysteresis and room temperature feedback was analyzed with simulation and measurement data. Because of frequent switching between heating and cooling this control strategy has a dramatic impact on the energy performance as well as on the wear of the actuator (valve).

2.2. Outside temperature compensated supply water temperature control

The "outside temperature compensated supply water temperature control" has been presented in [9,16]. This control strategy is a feedforward control, but the supply temperature is controlled with a PID feedback controller [17]. There are different variants of this control; however, the supply temperature of the TABS is always a function of the measured outside temperature. It is recommended to define different parameters for heating and cooling as well as for office buildings for workdays and weekends (because the internal loads differ significantly on these days). In [18] this control strategy was used for demand side management mechanisms realized through parameter adjustments of the heating and cooling curve. In advance, these heating and cooling curves can be adjusted for the building through appropriate planning tools and dynamic simulation programs and should be optimized based on experiences during operation. The planning tool "TABSDesign" (download at http://www.faktor.ch/tabs-tool.html) is a Microsoft Excel sheet and designed to simplify the planning and design process of TABS and to find the first parameters for this control strategy without taking demand side management mechanisms into account. It is specially adapted to the so-called unknown-but-bounded (UBB) method, which is described in detail in [19,20]. This is an integral approach that uses the outside temperature compensated supply water temperature control. The different variants are: