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Natural ventilation for passive cooling by means of optimized control logics

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Abstract

Natural ventilation is one of the most efficient solutions to improve thermal comfort in buildings, particularly for passive and hybrid cooling. This paper analyses the potential of building automation systems for ventilative cooling in residential buildings. In relation to internal and external temperature, an optimized control strategy of window opening is developed to ensure adequate levels of indoor thermal comfort, reducing energy consumption for cooling. In particular, the control of ventilation is calibrated by an optimized variable set-point and a Particle Swarm Optimization (PSO) method is adopted with objective function that minimizes the thermal discomfort hours. The PSO algorithm is implemented in MATLAB and integrated with TRNSYS energy simulation software. A case study focusing on an existing Italian typical building of the '60s, situated in the Mediterranean climatic context is presented. Thermal comfort analysis, according to the adaptive thermal comfort theory (EN 15251-2007), shows that the optimized control logics for natural ventilation determines a significant reduction of overheating discomfort in reference to the case with ventilation only for indoor air quality at fixed hours. Combining the passive cooling system with an active cooling, there are also reductions in energy consumptions for cooling. The results show how the proposed optimized control logics increase the potentialities of natural ventilation strategies to the improvement of energy and thermal performance of buildings, integrating or replacing the conventional efficiency strategies.

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Keywords: Natural ventilation; passive cooling; building automation; particle swarm optimization.

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Nomenclature

BA	Building Automation
BAS	Building Automation Systems
PSO	Particle Swarm Optimization
$T_{optimal}$	Optimal temperature
T_{indoor}	Indoor temperature
$T_{outdoor}$	Outdoor temperature
N_{heat}	Total discomfort hours for overheating
N_{cool}	Total discomfort hours for undercooling
s.f.	Shading factor
IAQ	Indoor Air Quality
HVAC	Heating Ventilation and Air Conditioning
NZEB	Nearly Zero-Energy Buildings
PMV	Predicted Mean Vote
U-value	Coefficient of heat transmission (W/m^2K)

1. Introduction

In the building sector, the energy used for cooling is taking on an increasing share in the energy balance especially in Mediterranean climate, as a result of the increasing use of mechanical conditioning device [1].

The adoption of passive solutions allows a significant reduction of greenhouse gases emissions and addresses the emerging trend of Nearly Zero-Energy Buildings (NZEB), according to the 31/2010 European directive [2]. Passive techniques, such as natural ventilation and solar shading, could satisfy the indoor comfort while minimizing the use of active systems in buildings. Natural ventilation is a low-cost passive solution able to guarantee both Indoor Air Quality (IAQ) and thermal comfort in buildings, by reducing the demand for mechanical ventilation and air conditioning [3]. Specific studies show that application of natural ventilation techniques may decrease the cooling load of buildings and improve indoor comfort and air quality. In particular, Boukhris *et al.* [4] study the natural ventilation as the main passive strategy to reduce overheating in the Tunisian summer climate. Moreover, in [5] four different ventilation strategies with the combination of various building envelope characteristics are simulated for hot-humid climate in Singapore.

On the other hand, in recent years, Building Automation Systems (BASs) associated with control and optimization techniques are widely used to reduce building energy consumption and improve indoor comfort [6], [7]. Many researches deal with the control of active systems, others both on active and passive systems, and only few researches focus on BASs for passive components. For instance, in [8] an intelligent controller is designed to determine the optimal ventilation rate in active systems, by maintaining the indoor CO_2 concentration in the comfort zone and by reducing energy consumption. Moreover, due to the non-linearity of the proposed model, Particle Swarm Optimization (PSO) is adopted to obtain the optimal ventilation rate: the relationship between the ventilation rate and the corresponding power consumption is described by fuzzy logic. Castilla *et al.* [9] propose a multivariable nonlinear model predictive control system to maintain thermal comfort and IAQ by means of Heating Ventilation and Air Conditioning (HVAC) systems and natural ventilation. The main control objective is to maintain users' thermal comfort and IAQ inside a comfort zone defined by the Predicted Mean Vote (PMV) and the IAQ indices, respectively, minimizing, at the same time, the energy consumption necessary to achieve this comfort. In addition, Sun *et al*. [10] propose an integrated control of active and passive heating, cooling, lighting, shading and ventilating system with the aim of minimizing total energy costs. To solve the optimization problem with the coupling HVAC capacity constraints, Lagrangian relaxation is used to obtain a near-optimal solution. In [11] the authors use for the control of the natural ventilation an energy management algorithm implemented in the Energy Plus simulation. In particular, the algorithm consists of the following three components: rules on indoor air quality based on CO_2 sensors, rules on thermal comfort to prevent the overcooling, rules to reduce the risk of air draft.