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# Parametric study on the advantages of weather-predicted control algorithm of free cooling ventilation system

Sašo Medved*, Miha Babnik, Boris Vidrih, Ciril Arkar

*Laboratory for Sustainable Technologies in Buildings, Faculty of Mechanical Engineering, University of Ljubljana, Aškerčeva 6, 1000 Ljubljana, Slovenia*

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ABSTRACT

Predicted climate changes and the increased intensity of urban heat islands, as well as population aging, will increase the energy demand for the cooling of buildings in the future. However, the energy demand for cooling can be efficiently reduced by low-exergy free-cooling systems, which use natural processes, like evaporative cooling or the environmental cold of ambient air during night-time ventilation for the cooling of buildings. Unlike mechanical cooling systems, the energy for the operation of free-cooling system is needed only for the transport of the cold from the environment into the building. Because the natural cold potential is time dependent, the efficiency of free-cooling systems could be improved by introducing a weather forecast into the algorithm for the controlling. In the article, a numerical algorithm for the optimization of the operation of free-cooling systems with night-time ventilation is presented and validated on a test cell with different thermal storage capacities and during different ambient conditions. As a case study, the advantage of weather-predicted controlling is presented for a summer week for typical office room. The results show the necessity of the weather-predicted controlling of free-cooling ventilation systems for achieving the highest overall energy efficiency of such systems in comparison to mechanical cooling, better indoor comfort conditions and a decrease in the primary energy needed for cooling of the buildings.



## 1. Introduction

Expected global climate change and increased heat island intensity in urban environments will result in increased energy demand for cooling of buildings. A review of the impact of climate change on energy demand in built environments in different climate zones was presented by Li et al. [1]. Xu et al. [2] analysed long-term energy consumption for the cooling of the buildings and concluded that electricity use for cooling could increase up to 50% until the end of the century. Frank [3] compared energy demand for the heating and cooling of multi-storey buildings for different climate change scenarios. He concluded that, in case of the most severe climate scenario (global temperature increase by 4.4 °C), the cooling period would be extended by up to 72 days a year. Vidrih and Medved [4] predicted the duration of the overheating period in residential and office buildings without mechanical cooling and the impact of natural night-time ventilation on the energy demand for cooling of the buildings by assuming different climate scenarios to 2050. They determined that natural ventilation could be efficient despite increased average ambient temperatures and decreased ambient temperature daily amplitudes in urban environments. The cooling potential of night-time ventilation was analysed by Artmann et al. [5] for different climate regions in Europe. Extended numerical and experimental research on night-time ventilation cooling in 214 flats in multi-family buildings was presented for hot southern European areas by Santamouris et al. [6]. Shaviv et al. [7] studied the influence of heat accumulation in the buildings on cooling with night-time ventilation.

Although natural nigh-time ventilation is energy efficient, this technique has limitations regarding the controlling of thermal comfort conditions, architectural restrictions of the building envelope and security requirements due to facade openings. Those disadvantages of natural cooling could be abolished by free cooling ventilation systems. Such systems also have advantages over mechanical cooling, because ambient night-time cold is used for cooling of the building, and the energy supply is only needed for fan operation. Because the availability of ambient cold is time dependent and its potential is limited, the operating efficiency of free

* Corresponding author. Tel.: +386 1 477 1237; fax: +386 1 251 8567.
*E-mail address:* saso.medved@fs.uni-lj.si (S. Medved).

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**Nomenclature**

*Symbols*

| | |
|---|---|
| $c_p$ | specific heat, kJ/kgK |
| $COP$ | coefficient of performance of cooling system, 1 |
| $f$ | weighting factor, 1 |
| $g$ | total solar energy transmittance, 1 |
| $G$ | solar radiation, W/m$^2$ |
| $\dot{m}$ | mass flow rate, kg/s |
| $n$ | air change rate, h$^{-1}$ |
| $n_{50}$ | air exchange rate at pressure difference 50 Pa, h$^{-1}$ |
| $P_{SFP}$ | specific fan power, kWs/m$^3$ |
| $PE^*$ | cost-weighted primary energy kWh/day |
| $\dot{q}$ | internal heat gains, W/m$^2$ |
| $\dot{Q}$ | heat flux, W |
| $Q$ | heat, kWh/day |
| $Q'_{mc}$ | specific cooling load, W/m$^2$ |
| $T$ | temperature, °C |
| $v$ | velocity, m/s |
| $U$ | thermal transmittance, W/m$^2$ K |
| $\dot{V}$ | volume flow rate, m$^3$/s |
| $W$ | electricity demand, kWh/day |
| $\Delta t$ | interval in numerical simulation, h |
| $\Delta T_{on/off}$ | on/off temperature difference, K |
| $\Delta T_{i,limit}$ | upper limit value of allowable indoor operative temperature, K |

*Subscripts*

| | |
|---|---|
| $EC$ | electricity cost |
| $fc$ | free cooling |
| $glob,0$ | global, measured on horizontal surface |
| $i$ | indoor |
| $max$ | maximum value |
| $mc$ | mechanical cooling |
| $min$ | minimum value |
| $o$ | ambient |
| $od$ | daily mean ambient |
| $pred$ | predicted value |
| $PE$ | primary energy |
| $rm$ | running mean |
| $wall$ | wall |
| $win$ | window |

cooling ventilation systems can be improved by introducing a weather forecast into the control algorithm. The weather forecast prediction approach is well known, for example, in electricity production [8] and energy-demand modelling [9], controlling of HVAC (Heating, Ventilation and Air-conditioning) systems [10] or controlling mechanical cooling systems [11].

However, research on the weather-predicted controlling of free cooling systems operation are rare despite the fact that the efficiency of such systems relies heavily on the time-dependent potential of natural cold. Wittchen et al. [12] studied the influence of weather-predicted free cooling on energy demand for the cooling, without taking into account the adaptive indoor thermal comfort requirements and overall energy efficiency of free cooling system. Dovrtel and Medved developed one-parameter [13] and two-parameter [14] optimization models for night-time cooling of cold storage integrated into the free cooling system operating with preselected constant air exchange ventilation rates, without emphasizing a comparison of the energy efficiency of the free cooling system comparing to mechanical cooling.

In addition to outdoor climate conditions that determinate the potential for free cooling, the indoor environment thermal comfort requirements have a large impact on the energy efficiency of free cooling systems. Therefore, adaptive thermal comfort models are predominantly used for the determination of indoor conditions. Yang et al. [15] compared different adaptive models and concluded that such models have significant influence on the energy demand for the cooling of the buildings. The most common adaptive model presented in EN 15251 [16] is used. Panão et al. [17] used this model to analyse the overheating of free-running buildings for six locations in Portugal.

In this article, a numerical algorithm for the controlling of a free cooling ventilation system operation is presented and validated on a small-scale building. The developed algorithm was used to study the importance of weather prediction correction that takes into account the site's micro-climate conditions, the influence of an adaptive thermal comfort model on the optimization of free cooling system operation and to show the advantages of free cooling in comparison to mechanical cooling of the building using the proposed cost-energy criteria for the case of a typical office building.

## 2. Weather forecast control algorithm of the free cooling system

Ambient cold, which is utilized by free cooling systems, is time dependent and limited in potential. Therefore, such systems should be not only carefully designed, but also advance controlled. Only in this way can a free cooling system operate at appropriate overall energy efficiency while simultaneously providing adequate indoor comfort. Weather forecast data could be used for the prediction of time-dependent night-time cooling potential and for the prediction of time-dependent building cooling load during the following day. Such an algorithm has been developed and is presented in the article. A flow chart of the free cooling ventilation system controlling algorithm is presented in Fig. 1. The algorithm is integrated into the TRNSYS (Transient System Simulation Tool) [18] simulation tool and is based on an iterative calculation of the thermal response of the building regarding the weather forecast for the following 24 h. In our case, the weather forecast is available on-line, twice per day (at 5:00 and 17:00) in half-hour time intervals. The forecast at 17:00 was used in the algorithm, because it covers the time interval that corresponds to the free cooling process during the night and the occurrence of the maximum indoor temperature during following day. The forecasted ambient temperature, $T_o$, the global solar radiation on the horizontal plane, $G_{glob,0}$, and the wind velocity, $v$, are used among the available meteorological variables. Because the local meteorological conditions could differ from nearest meteorological station's location (a 9 km × 9 km grid is used in the numerical modelling at the national meteorology office), the forecasted data must be corrected according the on-site measured data. The Kalman Filter method is used in our case [14].

In addition to building geometry, the thermal properties of the building, and the system operation conditions, the algorithm for weather-predicted controlling of free cooling ventilation system operation is based on several user pre-selected inputs:

- indoor comfort quality class regarding the classification presented in EN 15251 [13] for non-conditioned buildings; the selected class defined the acceptable range of maximum indoor temperature, $T_{i,max}$, regarding the running mean outdoor temperature, $T_{rm}$ [16]; it was assumed that the radiant temperature