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The impact of configuration and orientation of solar thermosyphonic systems on night ventilation and fan energy savings

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ABSTRACT

The scope of this work was to investigate the summer ventilation performance of three high thermal inertia solar thermosyphonic configurations, used as night natural ventilation systems. The aim was to assess the effectiveness of each configuration and orientation on night natural ventilation. Three designs, (a) SC1 a conventional SC, (b) SC2 a thermal chimney with duct attached behind the absorber, and (c) SC3 a thermal chimney rectangular duct with two surfaces glazed. Thermal performance of each SC was investigated by simulations in *EnergyPlus* followed by a Sensitivity Analysis performed on predicted results. For calibration and validation, output variables were checked and verified for coherence against published experimental data of similar nature found in literature. Analysis disclosed SC2 facing West the most effective design. Simulation results showed that a concrete thermal chimney 3 m tall with 0.1 m wall thickness and 0.2 m air gap exhibited night cooling capacity, depending on configuration and orientation, was found ranging from 3.27 MJ/m-day for the SC1 faced South, up to 10.0 MJ/m-day and 14.7 MJ/m-day for the SC3 and SC2 facing West, respectively. SC2 faced West was predicted to deliver flow rate 98% higher than the flow rate of a same size conventional SC1 faced South.

1. Introduction

1.1. Natural ventilation aspects

The worldwide ecological concern coupled with the late economic crisis has increased awareness regarding cost and environmental impact of energy use and reinforced people's interest to sustainable solutions. Natural ventilation (NV) systems have been proven most attractive for saving energy and money since they could improve indoor conditions with zero energy consumption, at a minimum cost. In warm climates, typical hourly air change rates (ACH) of 5–25 could be achieved in naturally ventilated commercial buildings with wind speeds 1–3 m/s [1], as an alternative to air-conditioning plants. Under favorable climate and proper building design, NV used as an alternative to electromechanical ventilation, could show savings 10–30% of total energy consumption [2]. Capital cost savings 18–65% have been indicated [3] in commercial buildings due to the large cost differential between night time cooling with mechanical ventilation or conventional air conditioning and night time cooling with NV. Utilization of NV systems is of great significance in saving money in residential buildings as well, particularly in hot and moderate hot and dry, or arid climates where outdoor night temperatures could drop below 20–22 °C. However, NV is ineffective in hot and humid climates where temperature swings between day and night are small because night cooling by natural ventilation offers only sensible cooling. So, if local climate is very humid, NV would probably increase day-time latent cooling loads by bringing in and accumulating indoors too much moisture during the night. In addition, one should not expect NV to provide indoor conditions comfortable for 100% of the time; for this, only finely controlled space conditioning systems are capable to achieve.

Solar chimneys (SC) are passive solar thermosyphonic systems enhancing natural ventilation in buildings removing indoor air by stack effect. Besides day-time use, a SC with massive heat storage walls is a natural ventilation device able to extend operation long after sunset, or exclusively be used for night cooling of internal environments. Such a cooling operation scheme could be particularly effective in hot and dry places, such as Attica, the Mediterranean regional location of Athens, Greece. In recent years, hot spells of considerable length and strength have appeared in Athens during summers, creating considerable discomfort and health hazard to civilians, Pantavou et al. [4].

In general, NV systems have benefits but also present drawbacks. Some benefits are: (i) energy costs [2,3] lower than air condition equivalents, (ii) increased fresh air supply that may

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result in higher thermal comfort and increased productivity, (iii) increased flexibility for spatial layout arrangements, (iv) low capital, low energy and low maintenance requirements. As drawbacks could be considered, (i) security reasons over opening windows, (ii) outdoor pollution, pollen levels, odors and noise owing to large façade openings, (iii) placement of screens required to keep out birds and insects leading to reduced ventilation potential, (iv) possibility that cooled surfaces could form condensation due to night increase of relative humidity, as in places near extended water areas. Also, the need for large non-shaded windows on S or W façade surfaces.

When asking the question, "*NV with cross ventilation, or solar chimney?*", the use of a SC presents some advantages, such as: (i) retaining occupants privacy, (ii) offering beneficial effects toward the establishment of indoor thermal comfort with low intensity indoor air movements; in contrast, cross-ventilation could cause noise and higher non-tolerable conditions if indoor air-speed gets greater than 1.0 m/s [5], (iii) keeping out all kinds of uninvited intruders, excluding dust, pollen and outdoor noise that may enter through façade openings and cracks, (iv) improving indoor thermal comfort in dry, cool and windless summer nights when cross ventilation is less effective or necessary. So, SC is an energy saving NV system of zero emissions and relatively low capital cost that, by its use, could save real estate owner's money by avoiding (a) utilization of larger size air-conditioning systems, and/or (b) the payment for extra façade openings to facilitate cross-ventilation; besides, installing a SC could be an ideal solution for providing ventilation to animal farm houses and hot houses located in rural areas far from electricity network.

In this study, *EnergyPlus* [6] software was used for running simulations on a naturally ventilated living space induced by a SC, where ASHRAE Standard 55 [5,7–9] have been taken into consideration. Information and references about Standard 55 were given, because it has become necessary to check thermal indoor conditions for thermal comfort against relative standards whenever passive systems are used in naturally ventilated buildings.

1.2. A short review of recent efforts

Many works have been published or presented, particularly the last two decades, illustrating a theoretical, numerical or experimental approach on the thermal performance of a SC. According to an article's subject extend and issue requirements, authors usually include in their paper references to relative works. Such informative and helpful to others task, regarding SC and other solar thermosyphonic systems, has been followed in recent studies of Dimoudi [10], Gontikaki [11], Baharvand [12], Bacharoudis et al. [13], Pavlou and Santamouris [14], Sakonidou et al. [15]. In the search for relative articles, one would discover that the majority of scientific studies are mainly entangled with day-time ventilation thermal performance of low thermal mass SC designs. But, in hot and dry or moderate dry regions, outside air is very warm, almost hot, during the summer day but gets rather cool at night. Therefore, day-time cooling by natural ventilation is of no benefit and it should be avoided. In these regions NV is more effective at night when ambient temperature drops and outside air could be used for ventilation beneficially. For this purpose a SC could be either attached to an outside wall, or placed on the roof. Articles illustrating SC configurations suitable for diurnal operation refer to SC types with high thermal mass, such as the Solar Wall Chimney (SWC) and stand-alone SC systems. SCs of high thermal mass can be found in studies of Barozzi et al. [16], Bansal et al. [17], Koronakis [18], Bouchair [19], Gan [20], Kumar et al. [21], Afonso and Oliveira [22], Bacharoudis et al. [13], Bouchair and Fitzgerald [23], AboulNaga and Abdrabboh [24], Marti-Herrero and Heras-Celemin [25], Macias et al. [26], Kaneko et al. [27], Dimoudi et al. [28], Marti-Herrero and Heras-Celemin [29], Matsumoto and Caram [30], Ong [31], Arce et al. [32], Kwang and Strand [33], Pavlou et al. [34], Khedari et al. [35,36].

There are various geometries and materials used for making a SC found in literature, i.e. Kumar et al. [21] studied a vertical SC of cylindrical shape placed at a distance from the ventilated space interconnected with an underground channel. Nevertheless, it is not of this work to refer to all of them. Some though have a special informative character. Among these articles, one could distinguish cases of SC designs capable to provide diurnal ventilation. Most of the works refer to SC systems of conventional design incorporating a single absorber wall of rather limited thermal storage capacity bearing a (South) S facing glazing cover. The effect of chimney wall height, thickness, duct cross-section and solar irradiance upon the diurnal ventilation performance of a conventional (non-glazed) chimney and of a SC with its southern wall surface glazed was presented in a full scale experiment [22]. Khedari et al. [35] investigated experimentally the natural ventilation effectiveness of door, windows and SC inlet openings to reduce house heat gains. The experiment referred to the cooling of a school-room using three S facing Wall Solar Chimneys (WSC's) and two roof-placed inclined SC's. A passive night natural ventilation cooling system for a social housing project in Madrid, enhanced by solar chimneys, was developed, implemented and presented in [30], using TRNSYS and TAS simulation tools for evaluation purposes. A hybrid two part analytical process was proposed in [22] to describe the diurnal thermal performance of a three-wall glazed SC with thermal inertia that was kept closed and solar heated during the day-time and naturally ventilated at night. Very useful information about the thermal performance of a SC with heat storage mass offering possible nocturnal ventilation benefit is presented in [19,20,24,28,30,32,37].

2. Scope and motivation

It is true that SC's have been investigated for various applications by a large number of researchers. It is also interesting that almost all researchers have investigated S facing SC systems which are effective mainly for day-time winter heating. In this study, we have tried to narrow the field of investigation to those SC configurations and orientations most suitable for night and/or diurnal summer operation. Figs. 1–3 are sketches of the lay out characteristics of the three horizontal cross-sections of SC1, SC2 and SC3 solar chimney configurations considered, respectively, all being constructed of reinforced concrete (heavy construction type) and protected by double glazing. Different sizes, wall thicknesses and air duct widths were considered. The aim was to indicate the most appropriate SC configuration and orientation for night ventilation cooling, ignoring the wind, uniquely based on stack effect. Naturally, it is widely recognized the importance and contribution of wind (actually, it is the pressure coefficient, C_p, value responsible) in providing natural ventilation to built spaces. Nevertheless, the role of a SC is to assist ventilation by the induced air due to the stack effect, thus increasing chimney efficiency by 10–23% [22].

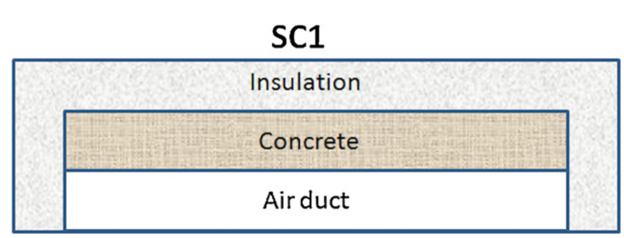

Fig. 1. Horizontal cross-section of the SC1 (conventional SC) configuration with the duct formed between the double glazed transparent cover and the absorber.