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Heat flows and energetic behavior of a telecommunication radio base station

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ABSTRACT

This paper shows a study on energetic consumption of BTSs (Base Transceiver Stations) for mobile communication, related to conditioning functions. An energetic "thermal model" of a telecommunication station is proposed and studied. The results have been validated with a BTS in central Italy, showing good agreement. Findings show a substantial high internal-external temperature difference in the containing shelter, particularly during daytime and warm months, due to sources of heat (equipment, external temperature and sun radiation) and to the difficulty in spread the warmth out. The necessity to keep the operating temperatures within a given range for the correct functioning of the electronic equipment requires the use of conditioning setups, and this significantly increases the energetic demand of the whole system. The analysis of thermal flows across the shelter can help to gather further data on its temperature behavior and to devise practical measures to lower the power demand, while keeping the operating parameters in the suggested ranges. The investigation of some operating parameters of the equipment and of the shelter, such as threshold set-points, air vent area, external wall transmittance and reflectivity, suggests annual energy savings between 10% and 30%.

1. Introduction

The technological development of the telecommunications sector goes hand in hand with the gradual increase of its energy consumption. In recent years, the focus has been to maximize the savings and use energy efficiently [1–5].

The BTS have a high-energy consumption due to the transmission equipment and the air conditioning of the shelter (the "building" that contains the transmission apparatuses). The energy consumption of the air conditioning system accounts for about 40–45% of that of the entire system [6,7].

Within the shelter, the thermo–hygrometric parameters, such as temperature and humidity, can be rather different from those recorded on the outside, due to the presence of many devices that dissipate energy as heat. However, they have strict operating parameters, and thus the use of machinery for air conditioning is indispensable to protect against dew and high temperatures.

The conditioning equipment must perform its task whilst taking into account energy savings [8].

Free cooling is a good opportunity for energy saving in air conditioning systems, due to its high efficiency. In fact, it is used when outside air is cool enough to be employed as a cooling medium [9]. It is usually of two types: air-side and water-side free cooling. The first introduces air into the shelter, whatever the conditions [10,11]; water-side, through cooling towers or dry coolers, is used to aid the outdoor air compressors in cooling the water supplied to the chiller system [12]. The use of these devices assists the air conditioning [13] and allows for good energy savings, especially during the transition periods (April, May, October) [9].

For the purpose of energy saving, it is also useful to set up correct management of the cooling systems, both through the diagnosis of abnormal energy consumption, due to errors in sensors or in cooling devices [14]; and through the correct setting of thresholds for the use of air conditioning systems [15], whereby, as shown in Ref. [16], it is possible to save up to 25% of cooling energy.

Other key elements for the study of thermo–hygrometric parameters within the shelter are the building materials.

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They must be chosen in relation to the climatic conditions of the area where the stations are located [17,18].

In this paper, we present a study of the temperature behavior of the shelters, concentrating in particular on the heat fluxes connected to them. This investigation is directed towards two goals: i) study of the energetic fluxes in the shelters; ii) optimization and dynamic control of the air conditioning systems. This paper models the power consumption associated with the conditioning of a station, studied through an algorithm that allows to outline the shelter as a thermodynamic system with heat fluxes (due to conduction, convection, and radiation) both towards and away from the building. The parameters that influence the thermal load of the shelter are complex and interconnected. The study and comprehension of the relationships between them is useful to develop systems that are able to simulate and predict the heat fluxes inside the shelter, in order to optimize energy consumption management [10,18–20]. To this end, hybrid energy systems with smart use of the cooling equipment have also been suggested [21].

With the algorithm, it is possible to change a series of parameters that characterize the shelter (the size of the free cooling window, the temperature thresholds of the conditioning system thermostats, the reflectivity of the building, the thickness and building materials for the walls and so forth.).

Therefore it is possible to study how each parameter affects energy consumption of the station and to evaluate the improvements that can decrease it.

The results were validated by monitoring a base station owned by the telephone service provider Wind, located in central Italy. They are consistent with results obtained elsewhere, both in Italy [6] and in other climates [10,18], and also in situations where a similar method was used to study energy saving when a thermosyphon heat exchanger is used [22].

2. Thermal balance of a shelter

A “thermal model” of shelters for telecommunication, including internal apparatuses and external contributions was created, to study its thermal balance. Therefore, it was possible to perform simulations, varying the factors that characterize the energy behavior of a BTS, to address the most effective parameters to lower energy consumption, recalling that the thermodynamic quantities (temperature, humidity, etc.) of a shelter for telecommunication can show a much wider range of values compared to places where there is human presence [7].

Assuming that the system is in thermal equilibrium with the external environment, the total heat flow in the system equals zero:

$$\Phi_T + \Phi_V + \Phi_{sol} + \Phi_{Cond} + \Phi_{St} = 0 \tag{1}$$

where Φ_T is the heat flux through the walls, Φ_V is the heat flux due to ventilation (also called free cooling), Φ_{Sol} is the heat flux due to solar radiation, Φ_{Cond} is the flux due to air conditioning and Φ_{St} is the heat flux released by the instrumentation (internal flow). The sign convention used here considers the entering heat flow as positive and expelled heat as negative. The energetic fluxes of a telecommunication shelter are shown schematically in Fig. 1.

As simplifying assumptions, the temperature is supposed to be uniform through the entire shelter (lumped temperature model) and all the parameters are supposed to be homogeneous and constant. Identically, the external temperature is supposed to be homogeneous. Higher order effects, such as wind on the external wall, are not considered; moreover, thermal properties of the walls are supposed to be homogeneous.

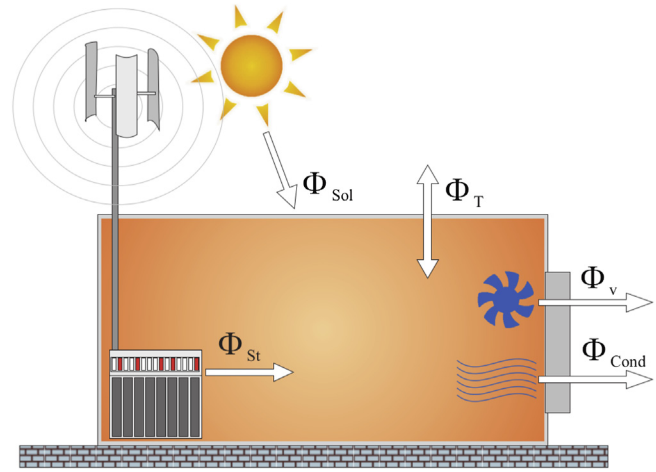

Fig. 1. Schematic representation of the energetic fluxes in the shelter (see text).

The flux contributions were modeled as follows [23,24]:

A. heat transfer through the walls.

This contribution is due to conduction and depends on the temperature difference between the inside and the outside of the shelter. Heath enters the system during the hottest days and sinks at night and on cool days. For this reason, this flow may be either positive or negative depending on the sign of the temperature difference:

$$\Phi_T(W) = A_{tot}*U*(T_{out} - T_{in}) \tag{2}$$

where U is the transmittance of the wall, T_{in} and T_{out} are the mean internal and external temperatures, respectively, and A_{tot} is the sum of the areas of the four side walls and the ceiling. The floor was neglected since there is no noticeable heat flow through it.

B. Heat flow due to ventilation (free cooling).

This input is due to apparatuses that expel hot air outside and pump the external air in. The advantage of these systems is primarily the use of low external temperatures to save energy during cold periods of the day/year. The only consumed electrical energy is the one used to power the fans. On cold days, this is the most efficient cooling method.

The heat flux due to free cooling is:

$$\Phi_V(W) = -H_v*V_a*\Delta T*A_{FIN} \tag{3}$$

where H_v is the volumetric heat capacity of the air. It depends on air density, $\rho_a = 1.2$ kg/m^3, and on the specific heat of air at constant pressure $c_a = 1000$ J/(kg K), so that $H_v = \rho_a * c_a = 1200$ J/(m^3 K).

V_a is the velocity of the incoming air; ΔT is the temperature difference between the inside and the outside. A_{FIN} is the area of the window of the free cooling system.

The negative sign indicates that this type of flow disperses energy towards the external environment. Practically, it is activated with pre-programmed thermostats.

C. Heat flow from solar radiation.

The sun radiation is accounted as:

$$\Phi_{sol}(W) = G*A*(1 - \rho) \tag{4}$$