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# Analysis of domestic hot water energy consumption in large buildings under standard conditions in Senegal

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## Abstract

This paper presents an investigation of the energy consumption due to domestic hot water (DHW) production in large buildings. We have studied three types of reference buildings: one office, one residence and a 3-star hotel located in Senegal. The DOE2.1E (the building energy program of the Department of Energy Version 2.1E) has been used. One of its main advantage is that it allows to take into account both energy end use categories and a great number of parameters of the building energy performance. Four climatic regions have been identified and their equivalent "standard" conditions are all defined. Those conditions are the same as the current design and operating conditions of each type of building. The DHW energy consumption is calculated and compared with the total energy generated by all end uses (lighting, cooling/ventilation, DHW, and other equipment). Before we carry out wide and systematic simulations of the three buildings energy performance, we pay special attention to check and validate the DHW part of the DOE2.1E model. There was an agreement between the recorded monthly DHW energy load on the one hand, and on the other the computed results. We end up finding results that could open new perspectives for building a strategic methodology to provide guidelines for DHW energy saving measures in large buildings in West Africa. Furthermore, it is expected that energy researchers concerned about energy and environmental efficiency would consider this study for promoting $CO_2$ emission reduction in relation with DHW production in large buildings.

*Keywords:* Domestic hot water; Buildings; Energy consumption; Energy efficiency; Energy code; Tropical Africa; $CO_2$ emission reduction

## 1. Introduction

Detailed studies of the primary energy consumption for cooling/ventilation, lighting and influence of the building envelope design were performed [1]. Adversely, it is noted that only few investigations which specifically deal with DHW energy consumption in large buildings have been carried out. Nevertheless, the fact of increasing the DHW energy system efficiency becomes necessary; particularly in Sub-Saharan Africa because of its rising urbanization and fast development of large buildings of various types (residence, hotel, office, medical, or multi-purpose types). Consequently, the market of DHW production and distribution equipment is growing steadily. Accurate assessment of DHW energy load is the first condition to make the DHW system efficient. Forecasting the load can be performed with different methods as for example the simple method of formulating load profile (SMLP) which produces a daily load profile [2], or the drawing schedule method and their substitutes [3,4].

The purpose of many other investigations was to design or improve the DHW renewable energy systems and equipment which can reduce consumption of fossil energy. Thus, some researchers have studied the utilization of solar water heating systems for district energy system with seasonal water thermal storage for both commercial and residential building [5]. They have also studied the utilization of heat pumps for water heating [6], or most generally, the development of DHW innovative systems of production [7–9]. In order to ultimately elaborate further measures of energy efficiency that could be implemented to the DHW system and plant equipment, it is consequently necessary to undertake systematic investigations with the help of an efficient tool that enables comparison between the DHW energy consumption and the other buildings end uses energy consumption.

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**Nomenclature**

| | |
|---|---|
| DHW | domestic hot water |
| CVAC | central ventilation and air conditioning |
| $P_{gen}$ | heating power (W) |
| $P_{sto}$ | rate of heat losses from the storage tank (W) |
| $P_{dis}$ | rate of heat losses along the distribution line (W) |
| $P_{ut}$ | useful power (W) |
| $D_s$ | coefficient of thermal losses of the tank (W/K) |
| $V_s$ | size of the storage tank (L) |
| $K_t$ | coefficient of thermal losses of the distribution tube (W/m K) |
| $L_t$ | length of the tube (m) |
| $h$ | tank equivalent exterior heat transfer ($W/m^2$ K) |
| $S$ | total exterior surface of the storage tank ($m^2$) |
| $T_{sto}$ | hot water average temperature inside tank (°C) |
| $T_{f\,min}$ | Minimal primary water temperature inside the tank (°C) |
| $T_{ambsto}$ | Ambient temperature around the storage tank (°C) |
| $T_{supply}$ | DHW supply temperature inside the distribution circuit (°C) |
| $T_{amb}$ | ambient temperature around the distribution circuit (°C) |
| $V_{ph}$ | volume of maximal DHW drawing for a few hours (L) |
| $N$ | number of taps or drawing devices (unit) |
| $s$ | Simultaneousness factor (unit) |
| $Q_s$ | DHW flow rate (L/s) or ($m^3$/h) |
| $Em_{ref}$ | $CO_2$ emission in baseline condition per $m^2$ of building (kg $CO_2/m^2$/year) |
| $Em_{opt}$ | $CO_2$ emission induced with mitigation options per $m^2$ of building (kg $CO_2/m^2$/year) |

For this purpose, we have used the DOE2.1E building energy program which has been designed under the coordination of Lawrence Berkeley laboratory in 1978. However, before running systematically this energy program, it was firstly necessary on the one hand, to especially validate its way of predicting the DHW energy load, on the other, to define the standard conditions for each of the three reference buildings considered in each of the four climatic regions. Therefore, the main objective of this study is to determine the values of the monthly or yearly specific DHW energy functions (thermal DHW load, electricity consumption to satisfy the load, DHW peak load, DHW peak electricity consumption) at the standard conditions, by using the DOE-2.1E building energy program. Consequently, the purpose of this study is first, to analyse how those specific DHW energy functions vary with the climatic region, and then to determine the importance of the DHW energy consumption in the energy performance of the building.

## 2. Material and methods

### 2.1. Description of the reference buildings

Three different types of existing buildings located in Dakar are considered as the reference buildings to be studied: a residence building (the"Immeuble rose", 3400 $m^2$, 5 floors), an office building (the "Immeuble SICAP", 2258.7 $m^2$, 7 floors) and a 3-star hotel building (the "Tabara" hotel, 2012.1 $m^2$, 6 floors). The investigation concerns four climatic regions in Senegal (Dakar, Kaolack, Tamba, and Ziguinchor).

We have decided to check and validate the DHW part of the DOE2.1E model, before the three reference buildings are widely analysed. It is firstly investigated the 3-star hotel building for which measurements and diagnostic results have been previously provided. Therefore, the validation is carried out solely for the hotel building.

### 2.2. The energy balance equation of the DHW system

The DHW system equipment consists in a primary water feeding system, a well insulated hot water tank equipped with electrical heater, a distribution circuit, circulating pumps and safety control devices as shown in Fig. 1.

As a first approximation, the DHW supply temperature is usually set equal to the DHW average temperature inside tank. During the steady state heating period, the heating power input $P_{gen}$ (W) is defined by the following energy balance equation:

$$P_{gen} = P_{ut} + P_{sto} + P_{dis}. \tag{1}$$

with

$$P_{gen} = 1.16 V_s (T_{sto} - T_{f\,min}), \tag{2}$$

and $V_s$ (L), $T_{sto}$ (°C), $T_{f\,min}$(°C) are, respectively, the size of the storage tank, the inside tank hot water average temperature and the ambient temperature around the storage tank.

The rate of heat losses from the tank $P_{sto}$ (W) at Eq. (1) can be determined [3] as follows:

$$P_{sto} = 24 D_s (T_{sto} - T_{ambsto}), \tag{3}$$

where the heat loss coefficient $D_s$ (W/K) is taken as follows:

$$D_s = (1.1 + 0.00005/V_s) h S, \tag{4}$$

with $h$($W/m^2$ K) and $S$($m^2$), respectively, the tank equivalent exterior heat transfer and the total exterior surface of the storage tank. $T_{ambsto}$ is the ambient temperature around the storage tank.