

Electricity consumption reduction by thermal insulation of buildings in hot climate

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Résumé

Ce papier porte sur l'importance de l'isolation thermique des bâtiments dans le climat chaud de la ville de Djibouti. Les performances thermiques et les consommations d'énergie comparées de deux chambres expérimentales construites au sein du CERD sont décrites. L'isolation testée dans le cadre de ce projet était l'isolation intérieure. L'une des deux chambres a été dotée d'un complexe isolant composé de 3 cm de polystyrène et 13 mm de plâtre. Une laine de verre de 5 cm d'épaisseur a été déroulée sur le faux plafond dans l'objectif d'atténuer le flux thermique en provenance du toit. L'autre chambre n'a été pourvue d'aucune isolation.

Le climat de Djibouti est particulièrement rude pendant les mois d'été et des moyens de rafraîchissement actifs (ventilation, climatisation) sont nécessaires pour éviter l'inconfort thermique qui en résulte. Ces moyens de rafraîchissement actifs consomment de l'électricité et les climatiseurs sont des équipements particulièrement consommateurs d'énergie. Il est clairement démontré dans plusieurs études que la demande électrique des climatiseurs est largement responsable du pic de la demande vers 14H et vers minuit pendant les mois d'été dans la ville de Djibouti. Tout programme de gestion de la demande énergétique (passif ou actif) qui aurait un impact sur le lissage du pic de la demande électrique serait intéressant pour la compagnie d'électricité. L'objectif de cette étude était de démontrer à l'échelle laboratoire que l'isolation thermique des parois et du plafond pourrait avoir un impact sur la réduction de la demande d'électricité.

Les campagnes expérimentales pour comparer le comportement des deux chambres et démontrer l'utilité de l'isolation thermique ont eu lieu pendant l'été 2008. Nous rapportons dans ce document quelques résultats essentiels obtenus lors de ces campagnes expérimentales. Ces résultats ont clairement démontré que des économies d'énergie allant jusqu'à 27% peuvent être obtenues avec l'isolation thermique et avec un climatiseur doté d'une régulation thermique (ici la température de consigne était réglée à 25°C).

La prochaine étape du travail sera de tester en conditions d'habitation occupée l'impact de l'isolation thermique sur la consommation d'énergie. Il sera alors question de procéder à l'isolation thermique d'une habitation déjà existante et comparer les consommations énergétiques avant et après l'isolation thermique. Néanmoins les résultats présentés dans cet article peuvent d'ores et déjà être appliqués au cas de bâtiments continuellement occupés comme les hôpitaux par exemple.

Les objectifs finaux des travaux de recherche concernant l'énergétique des bâtiments entrepris par le CERD sont :

- aider le ministère en charge du bâtiment à établir une réglementation thermique pour les nouvelles constructions
- aider les particuliers à la diminution de leur facture d'électricité
- contribuer au travail de la compagnie d'électricité pour lisser le pic de la demande d'électricité

Abstract

The present paper discusses the importance of thermal insulation in buildings in hot climate. The thermal performance and the energy performance of two rooms built in the renewable energy laboratory of Djibouti are reported here. One of the rooms is insulated with polystyrene and gypsum board on walls and glass wool in the roof while the other does not have any insulation. Results obtained shows that an important energy saving can be realized with such simple thermal insulation.

Introduction

Djibouti is a country which is hugely dependent of imported fossil fuel for its electricity generation. Despite very interesting solar energy, wind energy and geothermal energy potentials, almost all the installed capacity is assumed by heavy oil fired power plant [1, 2, 3]. Solar energy could be a serious alternative in urban areas and especially for household sector. The average daily global solar irradiation is equal to 5.38 kWh/m²/day [3]. But before using solar energy for electricity production in urban areas, we must see how we can drastically reduce energy consumption levels of actual buildings. In fact solar energy using can only be useful if it's thought in a maximum energy conservation way. The purpose of this work is about the reduction of air conditioners energy consumption in Djibouti. We have focused our study on air-conditioners because almost 45% of the total electricity demand is related to air-conditioners [3]. In fact in the summer period of the city of Djibouti (April-September), climatic conditions are rather a challenge for human bodies in term of extreme temperature (up to 45°C), dusty and hot winds and considerable variations of relative humidity (in average 40% in July and 80% in September) [4]. Those very difficult summer climatic conditions are responsible of the high electrical load of air-conditioners [5] which can be seen in the figure 1. This figure shows the daily load curves measured for two days of the 2004 year by the Djibouti Electricity Company. The first day (January 18) corresponds to the "cold" season of the city of Djibouti. The maximal temperature in January is around 29°C and most of the households don't use the air conditioner. The second day (September 19) corresponds to the summer period and maximal temperature can reach up to 40°C. The great difference in the electricity power demand is attributed to cooling devices such fans, fridges and mainly air conditioners. Air conditioners load contribute greatly to the peak in the power demand in the summer period in Djibouti [6].

Energy demand related to air conditioners is huge not only in Djibouti but in most of the countries with very hot climate. Al-Rabghi et al [7] report that energy demand for air-conditioners is tremendous for Saudi Arabia (hot and dry climate) and Prapapong V. et al [8] report that in Thailand (hot and humid climate) the energy demand for air-conditioning is a matter of concern.

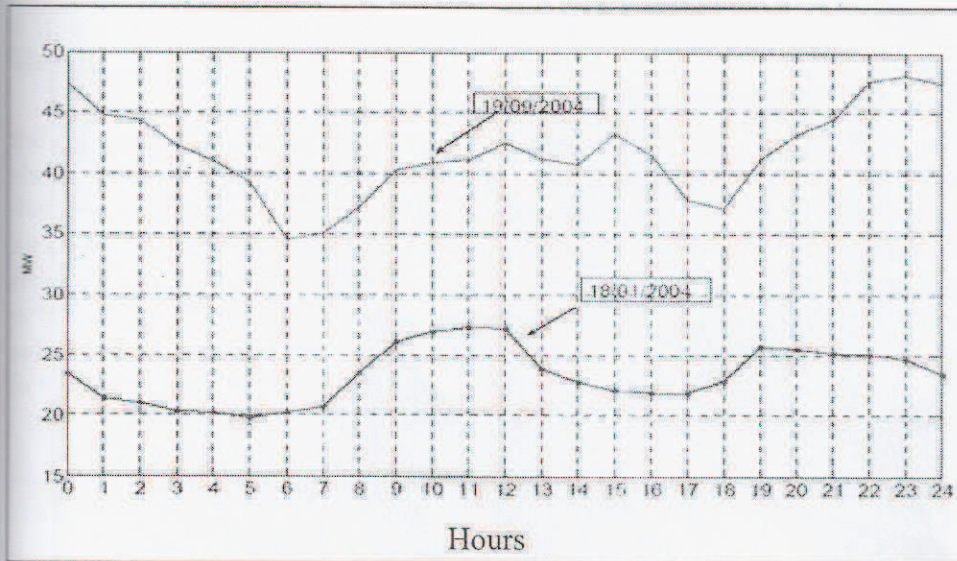


Figure 1: Daily load curves for a summer day and a "cold" season day

An ongoing survey that we are conducting shows that the average energy demand of air conditioners for a typical Djiboutian home is around 80 kWh/m²/year and can be as high as 100 kWh/m²/year in some cases. Those high values of energy demand are a consequence of the lack of any thermal consideration in the construction in Djibouti. In fact, despite very severe and hot summers, there's no thermal building code at this moment. Most of the homes use only one air conditioner for a typical cooling area of 30 m².

The energy consumption for building cooling is linked to three main parameters which are climatic conditions, the building characteristics (architecture, building materials) and the behaviour of the occupants. Among those three parameters we can only control the building characteristics and the behaviour of the occupants. In this work, we have tried to reduce energy consumption of a typical Djiboutian construction by changing the building characteristics. This can be done by changing the orientation of the building in order to receive the minimum of solar heat gain or by changing or upgrading the materials used for the construction. In this work we report how the using of a layer of a 3 cm polystyrene insulation and a layer of 13 mm gypsum board can drastically reduce energy demand of air conditioners in the summer climatic conditions in the city of Djibouti.

Method

In order to investigate the impact of thermal insulation on the electrical consumption of air-conditioners, two experimental rooms were built in the Renewable Energy Laboratory. We have compared experimentally the energy performance of the two rooms in the same climatic conditions and at the same time. The figure 2 shows a picture of one of the two rooms.

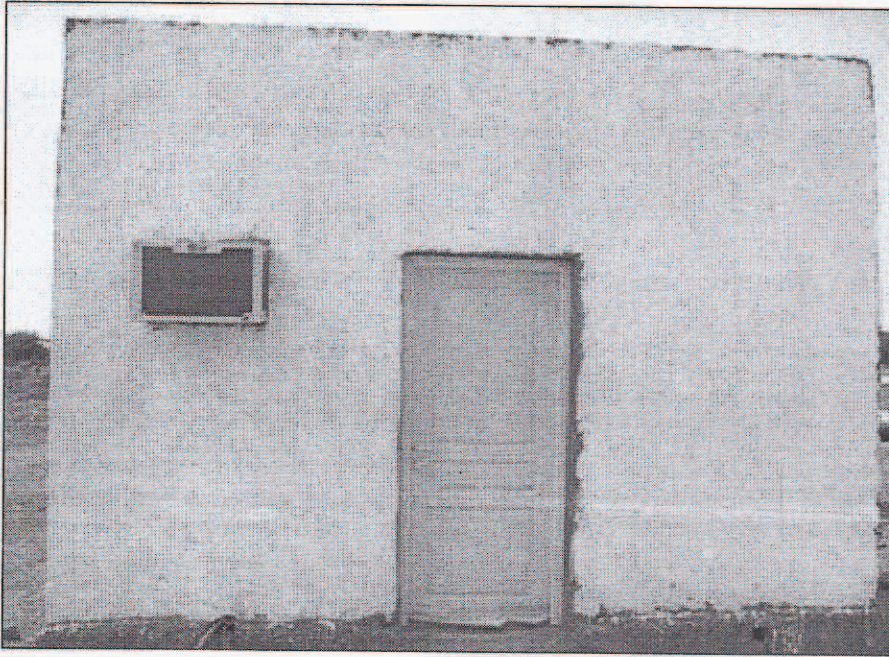


Figure 2: Photo of one of the two rooms

The first room is a widely used kind of construction in the city of Djibouti consisting of a cement brick wall and corrugated iron as a roof. Plywood is used as a roof ceiling. This type of construction does not have any kind of insulation. The second room is exactly the same as the first one described above but it has an insulation material consisting of a 3 cm layer of expanded polystyrene and a 13 mm layer of gypsum board for internal walls and 5 cm thick glass wool for roof. The two rooms are 4m*4m*2.5 m. For cooling purpose, each room has been equipped with a 1.2 KW rated window type air conditioner.

The two rooms were well instrumented. Each room temperatures (K type temperature sensor) and heat fluxes (with HFP01 sensor) of the eastern and western walls have been monitored. Temperature of the internal air has been recorded. External air temperature and global solar irradiation were recorded in order to determine the variation of the electrical consumption with variable climatic conditions.

Global solar irradiation was monitored with a LP02 sensor. In order to determine the energy performance, ABB energy meters have been used to record the cumulated electrical consumption of each air-conditioner. An Agilent 34970A data acquisition system was used for sensors readings, storing and monitoring. The goal assigned to the two air-conditioners was to maintain a set temperature of 25°C inside the rooms. For several days, experiments have been done and some of the obtained results are reported here.

Results

Results concerning the response of the two rooms and the air conditioners to the variation of external climatic conditions are reported in this section. The figure 3 shows the evolution of the external ambient temperature and the global solar irradiation received on a horizontal surface (the roof of the rooms) on a typical experiment day (on august 07, 2008). The graph (a) shows that external temperature can reaches challenging level¹ for human bodies. We can see in fact that this temperature is higher than 40°C for more than 6 hours in the day. In the graph (b) the global solar irradiation plot shows a pattern typically obtained with a partially cloudy day in the city of Djibouti.

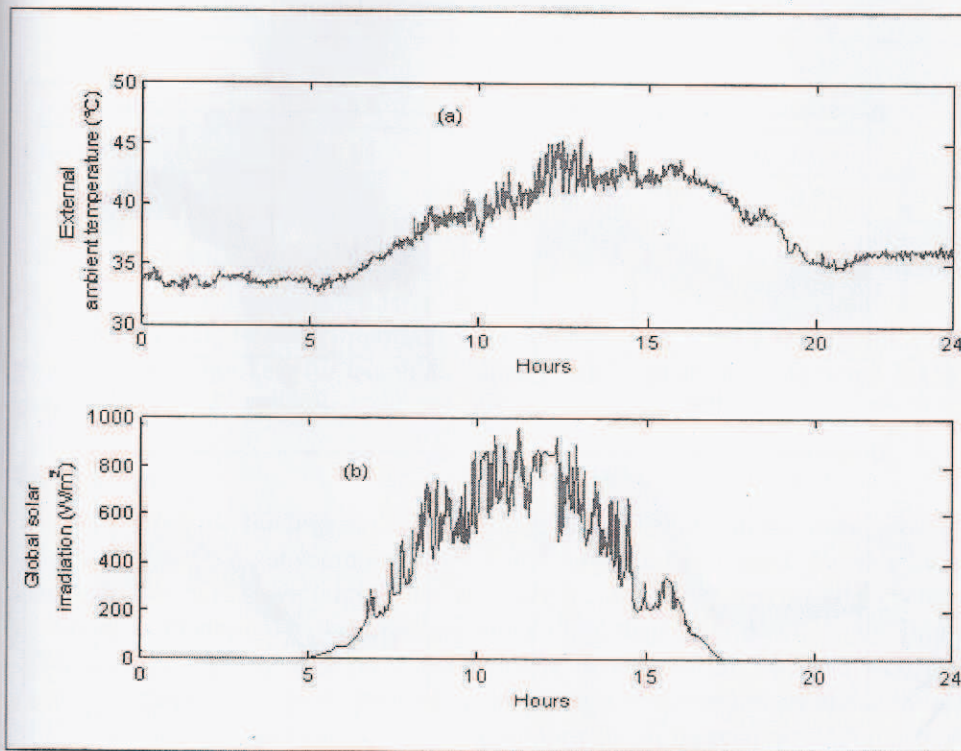


Figure 3: External ambient temperature (a) and global solar irradiation (b)

The external temperature and the solar irradiation are the two driving parameters for heat gaining of a building through heat transfer by convection with external air and heat transfer by radiation.

The figure 4 shows the response of the walls of the rooms to the variation of the external conditions. Eastern (a, d) and western (b, c) wall heat fluxes are plotted in this figure. It's clear from this figure that the walls of the two rooms have different responses. The walls of the non insulated rooms transmit more heat than the insulated one. It's a quite normal result since the quantity of heat transmitted is proportional to the thermal conductivity and the polystyrene is a thermal insulator.

The most important expectation that we was looking for was whether adding a thermal insulator would lead to a reduction of electrical energy consumption. The table 1 shows the energy consumption of the two rooms for twelve days experiments. The specific energy saving and the relative efficiency are defined as following:

$$\text{Specific energy saving} = \frac{\text{Non Insulated room energy demand} - \text{Insulated room energy demand}}{\text{Surface of the room}} \quad (1)$$

$$\text{Relative efficiency} = \frac{\text{Non Insulated room energy demand} - \text{Insulated room energy demand}}{\text{Non insulated room energy demand}} \quad (2)$$

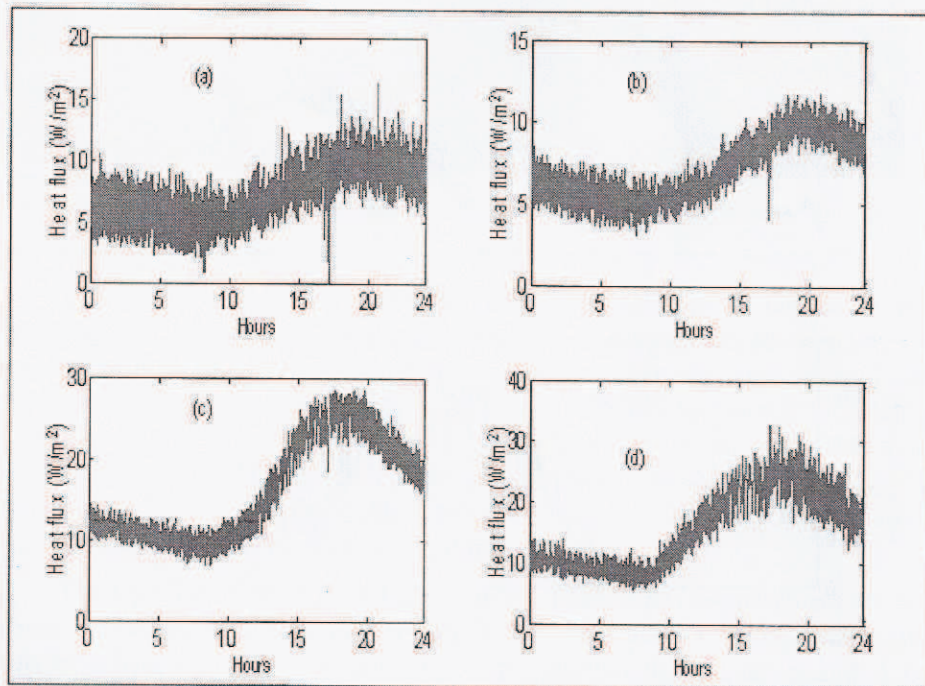


Figure 4: Eastern and western walls heat fluxes, (a), (b) for insulated room, (c), (d) for non insulated room

Depending of the external conditions, the energy consumption is not the same for each room. But for all of the days of the experiments, we can see clearly that the insulated room has lower energy demand than the non insulated one. The average energy saving for the twelve days is equal to 0.33 kWh/m²/day and the average relative efficiency is equal to 27%. That means that thermally insulated room can save energy up to 27% compared to non-insulated room and in the specific summer climatic conditions of the city of Djibouti.

Table 1: Energy consumed by the two air- conditioners (set temperature 25°C)

Day	Insulated room (kWh)	Non insulated room (kWh)	Specific energy saving kWh/m ² /day
05/08/08	16	21	0.31
06/08/08	12	15	0.19
07/08/08	14	19	0.31
08/08/08	15	22	0.44
09/08/08	14	20	0.38
10/08/08	15	21	0.38
11/08/08	12	17	0.31
12/08/08	15	22	0.44
13/08/08	15	20	0.31
14/08/08	14	20	0.38
15/08/08	14	18	0.25
17/08/08	15	20	0.31

This result is quite important for continuously cooled buildings like hospitals and supermarkets for example, which use a huge amount of energy for this purpose.

Discussion

In this work, the importance of using thermal insulator in the construction as an electrical energy consumption reduction tool has been assessed. The tick of the insulator used here is not large (3 cm only) but it can already provide up to 27% energy saving compared to classical non insulated buildings of Djibouti. In the future, other configurations should be tested such an increase of the insulator tick. This project was a part of a demonstration project dedicated for engineers and architects of Djibouti in order to aware them of the importance of thermal insulation. The final goal is to make buildings that would satisfy all of their energy demand by solar energy. Limiting the heat gain trough walls and roof is the first step on this way.

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