The impact of cost-efficient measures on the performance of school buildings in South Africa - Two case studies

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ABSTRACT

In 2005 the first Energy Efficiency Plan for South Africa was developed by the Department of Minerals and Energy [3]. This plan sets the target for energy efficiency improvements of 12% until 2015. One point of the strategy is to improve the energy performance of public buildings like schools. Many school buildings in South Africa are inadequate to provide a suitable learning and teaching environment for students. Within the scope of this paper two representative buildings of the education sector were analysed and assessed with regard to the construction of the building envelope and to the application of heating, air-conditioning and ventilation. Based on an analysis of the building envelope, the building service systems and of the indoor climate, various retrofit measures were evaluated and several ones realised. The effectiveness of the improvement activities were assessed by measurement series of the indoor temperature profile of retrofitted and unaltered reference buildings. The work has been performed within the EnerKey-project, funded by the German Ministry for Education and Research in cooperation with South African institutions.

KEYWORDS

Energy efficiency, School buildings, South Africa, Retrofit, Indoor climate

INTRODUCTION

South Africa is in the midst of an energy crisis. The national energy provider is not able to provide the currently demanded peak load capacity. This problem results in frequently occurred power blackouts especially in the metropolitan municipalities. The high peak demand is due to a large amount of energy which is used for conditioning of buildings. The reason for the high energy demand for building conditioning is due to the fact that neither the construction of the buildings nor the shading and building service systems are subject to any energy efficiency regulations. Another reason is the climate with medium to low temperatures in winter and high temperatures and high humidity in summer. The high solar radiation associated with huge internal heat gains by artificial illumination and inefficient appliances, requires arrangements for summer heat protections to avoid overheating in the classrooms. The EnerKey-project, funded by the German Ministry of Education and Research, aims in developing strategies to reduce the energy demand of the building stock in South Africa. In the first phase of this international project the energy performance of typical school buildings in South Africa was analysed. The importance of thermal insulation, air conditioning and ventilation is depicted on two selected case studies. As part of the study the buildings were analyzed and assessed with regard to the construction of the building envelope and to the application of air-conditioning and ventilation. Therefore questionnaires about occupants' perceived comfort levels were issued and evaluated and measurement series of the indoor temperature on several classrooms were conducted. Based on the results of the analyses of the temperature profiles and the evaluation of the surveys, cost-effective retrofit measures for comparable buildings were developed including aspects of thermal insulation and absorbance of solar radiation. The effects of the conducted renovation measures on the energy performance of the regarded buildings and their requirement for air-conditioning and ventilation were recorded and compared to the outcomes of not refurbished buildings.

DESCRIPTION OF ANALYSED BUILDINGS

The two selected case studies represent parts of the educational building stock of South Africa. The analysed buildings are located in the South African Province Gauteng, the Project area of the EnerKey-project.

Figure 1: On the left: Emmarentia Primary School in Johannesburg with brick walls, concrete floors and balustrades and a corrugated iron roof. On the right: Prefabricated classroom at Laerskool Garsfontein in Tshwane.

The Emmarentia Primary School, depicted in figure 1 on the left side, is a public educational institution which is mainly funded by the parents of the pupils. Only 10% of the school budget is provided by the Gauteng Department of Education The school building, located in the City of Johannesburg, consists of solid, not insulated brick walls, concrete floors and concrete balustrades and a corrugated zinc roof with a subjacent cardboard ceiling. The surface of the masonry and the roof cladding is quite dark, so that the building envelope shows a high solar absorbance. The windows are single-pane glazing with a metal frame with no thermal breaks. The frames are partially corroded and the conjunctions between window frame and masonry show to some extent big cracks. The school building has no external sun shading devices except the north facing façade, which is partially shaded by a corrugated iron awning. The windows are typically covered by dark curtains on the inside. Due to this interior sun protection the classrooms are very dark. Instead of daylight all classrooms are illuminated by artificial lighting. The heat supply of the school building is provided by a heating boiler charged with coal. The generated thermal energy of this central heating system, installed in the cellar of the school building, is not sufficient to provide all classrooms with thermal energy to create comfortable indoor climate, so that some classrooms need additional electrical heating units. Mechanical ventilation and cooling systems are not installed in the classrooms, except the computer room, which is conditioned by a peripheral air handling unit. Thus three north-facing classrooms without adequate solar shading are overheated in summertime. All classrooms are naturally ventilated by opening the windows.

Garsfontein Primary School, illustrated in figure 1 on the right side, consists of a brick structured main building and several prefabricated adjacent buildings. Focus of the conducted analysis was on the performance of the prefabricated classrooms. These buildings were erected in 1982 as temporary structures while the permanent solid school building was under construction. As the enrolment at the Garsfontein Primary School grew beyond the designed capacity of the permanent building, these temporary prefabricated buildings were used as classrooms further on. The buildings consist of steel-framed structures with fibrous cement panel claddings on the inside and outside. Between the two panels is an air space. Usually several cm of insulation is placed between the two layers. Because of bad execution and poor supervision, the insulation was not installed or slipped down so that a large area of the façade is uninsulated. The pitched and flat roofs of the prefabricated buildings consist of galvanised corrugated zinc roof sheeting. The subjacent ceilings of the single-storey buildings are constructed with gypsum cement panels. Between roof cladding and ceiling is an air space but no thermal insulation is installed. The windows are single-pane glazing with a metal frame without thermal break, which is typical of South African public buildings. On the northern side the classrooms are shaded by excess length of the corrugated zinc roof. To improve the thermal conditions in some classrooms electrical heating, cooling and ventilation units were installed but never used because of noise emission and instruction of the caretaker. The funding of the Laerskool Garsfontein is not sufficient for the service of the buildings, so that the greatest amount must be financed by the parents of the pupils.

ASSESSMENT OF INDOOR CLIMATE AND ENERGY PERFORMANCE

The Province Gauteng is located on the Highveld. The altitude of these area ranges from 1.330 m above sea level in Pretoria (Laerskool Garsfontein) to over 1.700 m above sea level in Johannesburg (Emmarentia Primary School). The climate of the region is mostly influenced by altitude. Even though the regarded school buildings are at a subtropical latitude (Johannesburg: 26,13° southern latitude), the climate is comparatively cool. In winter time – from June to August – the minimum outdoor temperature can fall under the freezing point. The outside air temperature in July averages to 10,0 °C [1]. As winter time is the dry season, snowfall is very rare. During summer time the outside air temperature can exceed 30°C. The mean temperature in January is about 19,9°C. Most of the annual precipitation of around 700mm occurs during the summer months. The annual mean temperature of Johannesburg is calculated to 15,9°C. Solar global radiation in the Province Gauteng reaches 1975 Wh/m²a. The monthly mean solar radiation intensity on a horizontal layer ranges between 163 W/m² in June and 279 W/m² in December.

Due to these climatic conditions, thermal insulation and air-conditioning has a great impact on the thermal performance of South African buildings during summer and winter. As descript in the preceding chapter, the regarded school buildings are poorly insulated, so that a lot of energy is needed for conditioning of these buildings to generate a comfortable indoor climate. Bruin et al [2] measured and analysed the thermal performance of the prefabricated classrooms of Laerskool Garsfontein. The results shown in figure 2 are indicative of the performance of prefabricated buildings. On two particularly warm days, when the outdoor temperature exceeded 30°C, the temperature was recorded in a 10-minutes time series. Each day, two series of measurements were collected, one in a prefabricated classroom with a flat roof and one in a prefabricated classroom with pitched roof and subjacent cardboard ceiling. The results of the temperature analysis are as expected. Due to the missing thermal insulation and due to a low heat storage capacity of building elements, the indoor temperature followed the exterior air temperature with almost no distortion of phase and exceeds the air temperature in the afternoon. Between 2:00 pm and 4:00 pm the measured indoor temperature in the flat roofed buildings reached 36°C. The sloped roofed buildings showed slightly lower indoor temperatures than the buildings with flat roofs. This is due to the air space between roof cladding and cardboard ceiling, which has a small thermal insulation effect for the conductive heat transport. The heat gain due to absorption of solar radiation by the dark surfaced roof and radiation of the absorbed thermal energy into the interior of the school building is not obstructed by any reflective layer. As the series of measurements were conducted while the classrooms are occupied for school lessons, the measured temperature profile was influenced by the user behaviour. The relevance of air exchange between inside and outside through opened doors and windows is not negligible.

A second measurement series to analyse the thermal performance of prefabricated buildings was conducted in the mid of spring season. The diurnal maximum outdoor air temperatures of the regarded days exceeded 15°C, during night time the temperature drop below 11°C. The solar radiation intensity at the afternoon of these analysed days was beyond 400 W/m². As depicted for hot exterior temperatures, the same differences between the thermal performance of flat roofs and sloped roofs were determined for colder temperature conditions. While the classrooms with a flat roof showed higher heat loses during night time and higher heat input during the day, the sloped roofed classrooms with the insulating air space showed a more moderate temperature increase and decrease over the day.

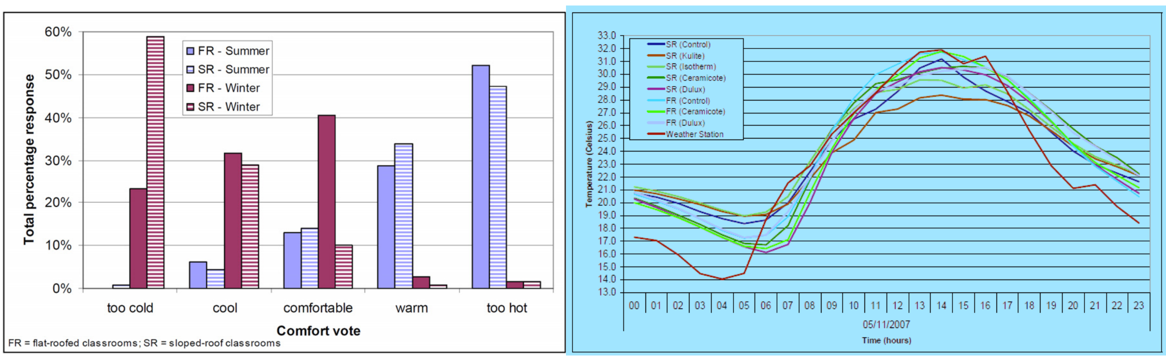

Figure 2: Left side: Student perceptions of the indoor thermal conditions during summer and winter periods. The results are divided into flat or sloped roofed buildings. Right side: Hourly average indoor temperature in prefabricated buildings before and after thermal improvement [2]

The conducted temperature measurements showed that the thermal performance of the school buildings is not consistent with a comfortable interior climate without the use of air-conditioning units. This conclusion was endorsed by the results of a conducted survey of the occupants. 239 students and 10 teachers participated in this survey about occupants' perceived comfort levels. The results of the survey are illustrated in figure 2. The results of the survey were evaluated separate for each type of roof. Nearly 60% of the interviewed persons quoted, that the indoor temperatures of the sloped roofed classrooms were too cold during winter season. In contrast to that only 20% of the interviewed in flat roofed classrooms characterized the indoor temperature as too cold during the winter time although the measured temperature did not exceed 18°C. The perceptions of the thermal conditions during summer were nearly similar for both roof types. More than 80% of the interviewed persons had the perceptions that the interior climate was warm or too hot during summer.

The school building of the Emmarentia Primary School has a comparatively good building structure with a high heat storage capacity of the brick walls and of the concrete floors. The pitched corrugated roof is quite similar to the structure of the sloped roof of the prefabricated buildings of Laerskool Garsfontein, descript in the preceding passages. While the Laerskool Garsfontein buildings show a lot of weak building elements which have to be improved to achieve an adequate indoor climate for the students, the weakest part of the Emmarentia school building is beside the single-pane glazing windows the corrugated uninsulated roof. In the following the study will be focused on the improvement of corrugated iron roofs which are the common thermal failure point of the studied school buildings.

APPLIED MEASSURES TO IMPROVE ENERGY PERFORMANCE

To improve the thermal conditions of the prefabricated buildings of the Laerskool Garsfontein, the influence of several retrofit measures have been studied [4]. The aim of the study was to find a solution for low-cost energy efficiency measures with minimal disruption of the school lessons. Based on a rough estimation of the potential of several energy efficiency retrofits, two interventions were selected. The first measure was the insulation of the pitched corrugated iron roofs to reduce the thermal conductivity of the roof. For this purpose two different insulation products were chosen. One product was a 50mm thick polyethylene blanket, the other one was a rigid expanded polystyrene board with a reflective aluminium foil on the upper side. The second retrofit measure was an application of a new white paint on the roof surface to increase the reflectivity of the iron sheeting. This measure could be conducted on sloped roofs as well as on flat roofs.

The achieved results of the retrofit measures were as expected. While the application of a new bright painting on the roof surface led to a reduction of the indoor temperature by two degrees in summer, the classrooms which were insulated by insulation with reflective foil on the upper side achieved a reduction of 3,5K. The insulation without a reflective foil achieved nearly the same improvement of the thermal performance as the white painted roofs with a temperature reduction of 2,0K. For a temperature reduction of 1K the insulation costs amounted to R187 for insulation with reflective foil and to R112 for polyethylene blanket insulation. The costs for a bright painted roof amounted to R93 per 1K reduction.

For the winter period the three retrofit concepts showed an expected difference in their effectiveness. While the range of the indoor temperature of the insulated classrooms were depressed so that the minimum temperature in night was higher than the indoor temperature of the reference building and the maximum interior temperature of the day was reduced. The bright painted roof led to a decrease of the indoor temperature of up to 3K during night and day.
An alteration of the roof shape of the flat roofed buildings is discussed. This could reduce the overheating risk of the classrooms by enlarge the air volume. An installation of ventilation openings at the highest point of the ceiling could also improve the ventilation, cooling and lighting situation.

CONCLUSION

The public building stock of South Africa and especially the educational buildings has a great potential for energy efficiency retrofits. Normally the building envelopes have no insulation and the used materials and shading systems are often inefficient to ensure a comfortable indoor climate. So far the bad thermal performance of the building envelope was compensated by electrical air-conditioning devices and electrical heating units which led to high electrical peak loads and so to frequently occurred blackouts of the electricity supply. The analysed and applied cost-effective retrofit measures could achieve an increase of the thermal performance of the analysed buildings and a reduction of the energy demand for conditioning of buildings. Especially the application of thermal insulation with a reflective foil on the upper side which reduces the absorbance of thermal radiation between roof cladding and the subjacent thermal insulation showed a respectable improvement of the indoor climate of prefabricated school buildings. The application of bright painting on the roof surface is a good and cost-effective solution to reduce the overheating risk in summer.

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