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Lighting level and room temperature audit of a University Campus

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ABSTRACT

An energy audit on a campus was conducted focusing on two parameters: lighting level and temperature. A walk-through survey for each room was done to measure the said parameters. The measurements were then compared with existing standards. It was found out that most of the rooms have lower than the standard average illumination. Meanwhile, there are rooms that have temperatures higher than the recommended values. Proposed improvements include adding lamps and change of T8 to T5 fluorescent bulbs. To address high temperature in the building, simple solutions like door closers and PVC roll curtains are suggested. Further study on the airtightness of the buildings and surface reflectance is recommended.

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1. INTRODUCTION

The energy demand has been seen to continually increase. The Energy Outlook 2022 report shows that the global primary energy consumption is seen to considerably grow over the next three decades. Along with the increase in demand, there is also increase in Brent crude oil prices from \$71/bbl in 2021 to \$120/bbl as of March 2022 [1]. The average wholesale electricity prices in the 4th quarter of 2021 were more than four times as high as the average for the last 5 years [2].

The consumers are greatly affected because changes in oil prices impact inflation rates [3] cascading an effect on the energy market. Although, there has been a revolution in the use of renewable energy sources and novel technological innovations, the world's dependence on oil remains [4]. Therefore, as a primary commodity to power industries, people must look at how to use energy more wisely. Energy efficiency is a must in these modern times [5], not only on the economic side, but also for ecological and social importance [6].

To attain this, energy and environmental audits are employed to identify the building weaknesses and to provide potential improvements [7]. The first thing to do is to examine how much energy is consumed and later used the data to optimize energy consumption [8]. One of the commonly used types is the walk-through energy audit which begin with the assessment of energy consumption of the building with the corresponding costs based on bills-invoices. It is often accompanied by a short on-site survey. Next, minimum investments on energy-saving options, which will make a direct economic impact, are determined while energy-saving opportunities with significant costs are proposed on a cost-benefit basis [9]. These audits are crucial part of an effective energy management program through proactive and systematic coordination of procurement, conversion, and distribution with full attention to environmental and economic objectives. The purpose is to monitor and control processes to maintain a certain level of energy expenditure in the building or organization [10].

Among other structures, university buildings could have a high value as models to start energy retrofitting programs [11]. According to a government-supported energy audit conducted in old school buildings in Slovenia, the industrial sector will be able to save possible energy savings for, on average, 15% or 12%, using measures where the pay-back period is shorter than three years. The possible energy savings in public buildings is about 31%, or 7% when the pay-back period is shorter than three years [12].

It is also interesting to note that energy audit is not only about figuring out the direct actions that are most effective in lowering costs [13], saving energy but also looking at the dwellers' comfort for a healthier living quality and efficient working environment for dwellers [14]. Students spend up to 25% of their time in educational buildings [15]. As part of the non-residential block where users stay a long period of time [16], there is heavy dependence especially on heating, ventilation, and air-conditioning (HVAC) systems. HVAC systems play a key factor in overall operational costs [17]-[19]. Air-conditioning units alone contribute to 34% of the total energy consumption while 18% for lighting loads [20], [21]. Additionally, proper lighting conditions should also be a priority since lighting affects student gains in reading [22] and concentration [23] while test scores may be affected by their classroom ventilation rate and temperature [24]. There have been a lot of improvements in the buildings of the university under study, however, despite these changes, faculty members and students alike comment on how uncomfortably warm the air feels in some of the rooms and the lighting conditions seem to be low. To properly address the issue, an energy audit was undertaken.

The contribution of this study is anchored in providing corrective action plans for the administrators of the campus. Unlike studies mentioned, the present study does not show at once the decrease in energy consumption if proposed improvements are carried out. To make a holistic energy conservation approach, the researchers will still have to carry out other components of the energy audit before decrease in energy consumption will be computed to make a comprehensive report encompassing all factors. The aim is to reveal areas on where to start the improvements and determine other factors contributing to inefficient energy use. The effect in student gains, concentration and test scores will not be included. However, these references will be part of justification for the administration of the university to evaluate the buildings. The locale of the present study is a tropical country while some studies were done in countries where there is winter. Still, they are important bases in the implementation of effective energy audits on educational buildings to identify suitable solutions aimed at reducing their high energy consumption since HVAC systems are also in their list of top usage.

The main purpose of this study is to address first the concerns of students and faculty members regarding lighting and temperature conditions. The objectives are as follows: i) evaluation of lighting levels, ii) evaluation of room temperatures, and iii) proposed improvements based on the findings.

2. METHOD

The study follows the methodology of an energy audit which refers to the inspection, verification, analysis, and evaluation of the physical processes including financial aspect of energy use in line with the provisions of local and/or international standards. This type of audit aims to properly manage energy systems for efficient energy usage [25]. In this study, the researchers focused on the illumination levels and room temperature of the rooms under survey. Figure 1 shows the paradigm of the study.

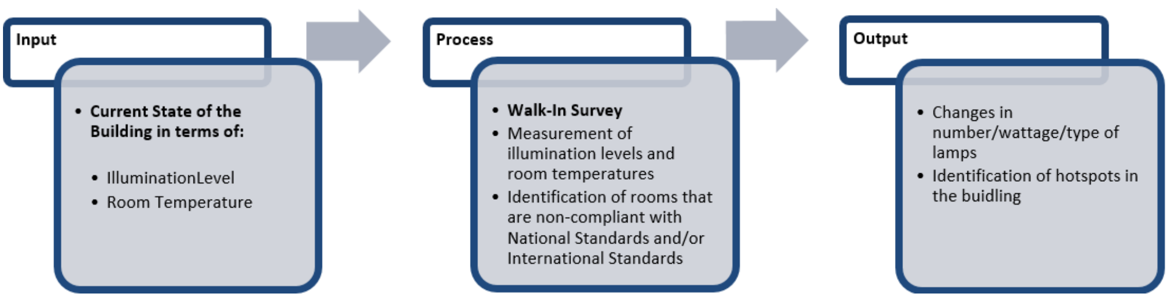

Figure 1. Paradigm of the study

Two buildings of the College of Engineering and Technology, Tarlac State University, Philippines is the focus of the audit. A walk-through survey was done to determine the number of measuring points for each room, after which, illumination measurements were taken using a lux meter while room temperatures were recorded using a thermometer. The data obtained were compared to standards to determine rooms with non-conformities.

Standards for illumination and temperature were based on existing manuals. For offices and school rooms, illumination levels should be 320-750 lux (lumens per square meter) [26]. Meanwhile, based on the American society of heating, refrigerating and air conditioning engineers (ASHRAE) standard 55-2017, temperatures could range between approximately 67 °F (19.44 °C) to 82 °F (27.78 °C for thermal comfort purpose [27]. For the computation of required number of lighting fixtures, in (1) was used by the researchers.

$$No. of\ Fixtures = \frac{E \cdot A}{O \cdot CU \cdot MF} \tag{1}$$

Where E is the required illumination in lux, A is the working area in m^2, O is the luminous flux produced per lamp in lumens, CU is coefficient of utilization, and MF is the maintenance factor.

3. RESULTS AND DISCUSSION

3.1. Lighting levels

Table 1 shows the lighting levels and lamp types/wattages in building 1. The first digit of the room number refers to the floor level, so rooms 103 to 113, including Library$_3$ can be found on the first floor. The subscripts indicate partition of a room as in the case of Library$_1$, Library$_2$, and Library$_3$. Meanwhile, the Stentorian Office and rooms 214 to 217 can be found on the second floor of the building. About 54% of the rooms in building 1 do not comply with the minimum recommended illumination level. These rooms include 103_2, 104 (lecture room), room 105, 106, 108, 109, 110, 111, 113B, Library$_3$, 207, 208, 209, 210, 211, 212, 213, Stentorian Office, 214, 215 and 217.

Table 1. Lighting levels and lamp types/wattages in building 1

Location/Area	Average illuminance (Lux)	Installed lamps (Type/ Watts)	Remarks based on average illuminance
101	382.438	8-FL T5 28 W	Compliant
102	348.5	15-FL T5 28 W	Compliant
103_1	391.94	7-FL T5 20 W	Compliant
103_2	212.063	8-FL T5 28 W	*Not compliant*
104 (lecture room)	216.563	8-FL T5 28 W	*Not compliant*
104 (laboratory room)$_1$	396.11	20-FL T5 28 W	Compliant
104 (laboratory room)$_2$	324.375	12-FL T5 28 W	Compliant
105 (lecture room)	309.1	40-FL T5 28 W	*Not compliant*
105	228.8	22-FL T5 28 W	*Not compliant*
106	278.24	14-FL T5 28 W	*Not compliant*
107	345		Compliant
108	303	24-FL T5 28 W	*Not compliant*
109	273.625	12-FL T5 28 W	*Not compliant*
110	280.64	18-FL T5 28 W	*Not compliant*
111	221.8125	12-FL T5 28 W	*Not compliant*
112	392.4375	12-FL T5 28 W	Compliant
113A (lecture room)	332.625	12-FL T5 28 W	Compliant
113A (laboratory room)	441.94	8-FL T5 28 W	Compliant
113B	254.0625	12-FL T5 28 W	*Not compliant*
114	358.25	16-FL T5 28 W	Compliant
Library$_1$	370.24	59-FL T5 28 W	Compliant
Library$_2$	469.375		Compliant
Library$_3$	267.1		*Not compliant*
Library Office	421.7		Compliant
Organization Office	385.3125	12-FL T5 28 W	Compliant
202	689.02	32-FL T5 28 W	Compliant
203	681.81	32-FL T5 28 W	Compliant
204	512.4	18-FL T5 28 W	Compliant
205	659.2	18-FL T5 28 W	Compliant
206	747.94	18-FL T5 28 W	Compliant
207	281.61	20-FL T5 28 W	*Not compliant*
208	308.68	24-FL T5 28 W	*Not compliant*
209	312.04	16-FL T5 28 W	*Not compliant*
210	227.04	16-FL T5 28 W	*Not compliant*
211	305.04	16-FL T5 28 W	*Not compliant*
212	212.36	20-FL T5 28 W	*Not compliant*
213	310	20-FL T5 28 W	*Not compliant*
Stentorian Office	258.44	2-LED Tube T8 20 W	*Not compliant*
214	198.5	20-FL T5 28 W	*Not compliant*
215	204	16-FL T5 28 W	*Not compliant*
217	210.8	18-FL T5 28 W	*Not compliant*

Meanwhile, as shown in Table 2, approximately 89% of the rooms in building 2 have lower than the standard measurements of lighting levels. Only rooms 202 and 208 have values within the standard. The scenarios for the two buildings can be corrected by considering daylighting and smart devices. However, case studies of such control systems for lightings are often found to be poorly implemented, calibrated, or commissioned, or perhaps too complex [28]. And so, the researchers started at the very basic improvements. As observed in both tables, lamps used in building 1 were T5s while building 2 have about 56% T8 fluorescent bulbs. In this case, there should be replacement of the T8 bulbs since each T5 lamp offer 21 W load reduction versus T8s [29].

Table 2. Lighting levels in the Aguinaldo Hall

Location/Area	Average illuminance (Lux)	Installed lamps (Type/Wattage)	Remarks based on average illuminance
101	172.625	9-FL T8 36 W	*Not compliant*
102	105.8125	9-FL T8 36 W	*Not compliant*
EE/ECE Faculty	273.625	9-FL T8 28 W	*Not compliant*
Dean's Office	299	8-FL T8 36 W 7-FL T5 28 W	*Not compliant*
CET Research Extension Office	82	2-FL T8 36 W	*Not compliant*
CE Faculty	261.1875	9-FL T8 36 W	*Not compliant*
Accreditation Room	267.125	9-FL T8 36 W	*Not compliant*
ME/IE Faculty	296.4375	9-FL T8 36 W	*Not compliant*
202	438.8128	9-FL T5 28 W	Compliant
204	118.81	4-FL T5 28 W	*Not compliant*
206	227.3125	9-FL T5 28 W	*Not compliant*
207	186.375	7-FL T5 28 W 2-FL T5 36 W 20-FL T5 28 W	*Not compliant*
208	410.1875	6-FL T5 28 W	Compliant
Hallway (Ground floor)	101.875	2-FL T5 28 W	*Not compliant*
Hallway (Second floor)	73.11	9-FL T8 36 W	*Not compliant*
Red Cross Office	94.22	9-FL T8 36 W	*Not compliant*

3.2. Room temperatures

Room temperatures in the buildings range from 23.1 to 31 ºC. Figure 2 shows that there are 27 out of 70 rooms (39%) which are beyond 28 ºC. A temperature setting beyond 24.5 ºC is already found to be uncomfortable [30]. Although in the Philippines, 25 to 26 ºC is still an acceptable temperature [31]. Further investigation reveals that the sizes of the air conditioning units in these rooms are enough to keep the room cool but are not operating in their full capacity due to issues in the electrical system. The varying voltage in the system contributes to the malfunctioning of some ACUs.

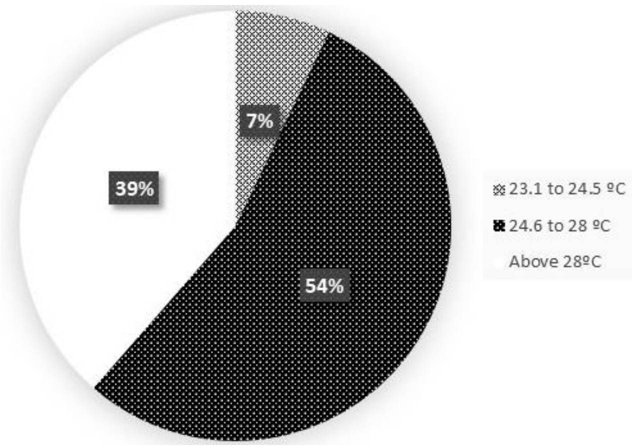

Figure 2. Room temperatures in building 1 and 2

In addition, heating factors in the building include doors that do not close properly and direct sunlight that penetrate the glass windows. Figure 3 shows the temperature map in the buildings. The red color indicates temperatures higher than 28 ºC. It can be noticed that rooms have varying colors indicating uneven temperature inside the room. It must be noted that building 1 is at least 53 years old while building 2 is at least a century old. Old buildings tend to have issues in airtightness [32]. Considering the number of occupants in the room, classes in the said campus typically have 45-50 students, sometimes up to 60. The information on the density of occupants is a vital input for further studies regarding energy efficiency index [33].

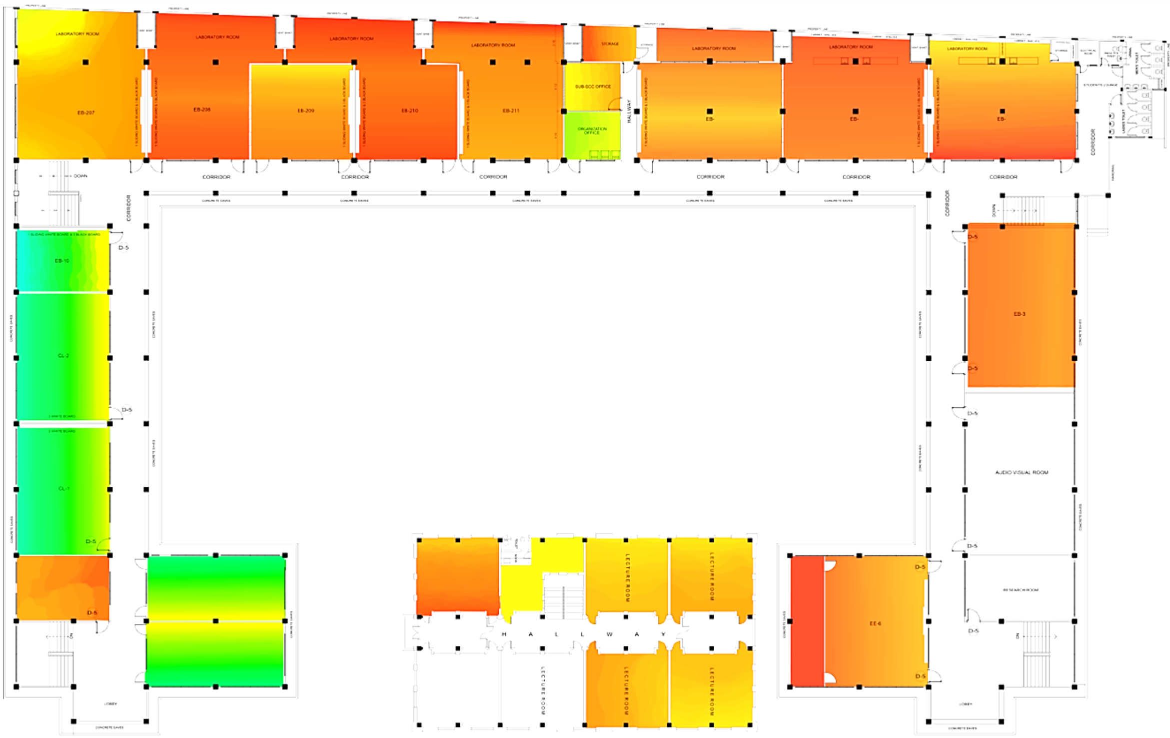

Figure 3. Temperature map of the campus

Meanwhile, some rooms accounting to 7% of the total number of rooms in the campus, such as rooms 202 to 206 in building 1 and the Dean's Office and accreditation room in building 2 have temperatures ranging from 23.1 to 24 ºC. These are the rooms with green or yellow colors as shown in the figure. The said rooms have tinted glass windows and there is a structure blocking direct sunlight. Based on recommended values, the rooms are within the acceptable thermal limit. However, the administrators could investigate these rooms for energy-saving opportunities by maintaining a minimum of 25.0 °C of room temperature. A similar study showed that increasing the room temperature by 1 °C may provide considerable cooling energy savings of more than 13% [34].

3.3. Proposed improvements
3.3.1. Lightings

Separating the rooms with non-conformities, the researchers measured the dimensions of the rooms and computed the required illuminance. Table 3 indicates the proposed number of lamp fixtures and that rooms 104 (lecture room), 109, 111, Stentorian Office, and 217 need either additional or change of lamps. The other rooms have appropriate installed lamps but have actual average illuminance below the standard. The Stentorian Office is suggested to change its lightings from 2-LED Tube T8 20 W to 4-FL T5 28 W for uniformity and easier procurement processes.

The same scenario can be seen in Table 4 as there are rooms which follow this pattern. At the time of survey, there are rooms which are installed with T8 lamps. The researchers proposed to change them to T5s for lower energy consumption and faster procurement of items as well. It is interesting to note that the Dean's Office has a total of 15 lamps and is recommended to be reduced to 11. In this case, there is an energy-saving opportunity in this room.

In the case of rooms that do not have the required illuminance despite having correct number of lamps, one obvious solution to address the issue is to clean the lighting fixtures periodically as dust can affect the efficiency of the lamps. However, there should also be consideration of surface reflectance of objects in the room. A study on the effects of surface reflectance and lighting design strategies on energy consumption and visual comfort concluded that although the type of luminaire is the prime factor in determining the quantity and quality of light in an indoor setting, it is also mentioned that increasing the indoor surface reflectance have a possibility of up to 45% energy savings while not sacrificing visual comfort. The paper also stressed that there is no single solution so there should be different strategies depending on the type of task and occupant's activities [35]. Hence, each room must be considered depending on its function and layout.

Table 3. Required illuminance of the rooms in building 1

Location/Area	Length (m)	Width (m)	Height (m)	Actual average illuminance (lux)	Required illuminance (lux)	Installed lamps (Type/Watts)	Proposed lamps (Type/Watts)
103b	5.7	5.7	2.5	212.063	401.94	8-FL T5 28 W	8-FL T5 28 W
104	7.7	5.7	2.5	216.563	469.74	8-FL T5 28 W	12-FL T5 28 W
105	17.1	10.7	2.5	228.8	447.33	40-FL T5 28 W	40-FL T5 28 W
106	8.5	10.7	2.5	278.24	462.88	22-FL T5 28 W	22-FL T5 28 W
108	8.9	11.4	2.5	303	458.34	24-FL T5 28 W	24-FL T5 28 W
109	9.5	8.55	2.5	273.625	371.19	12-FL T5 28 W	16-FL T5 28 W
110	10.1	9	2.5	280.64	378.92	18-FL T5 28 W	18-FL T5 28 W
111	11.3	6	2.5	221.8125	427.49	12-FL T5 28 W	16-FL T5 28 W
113B	5.6	8.5	2.5	254.0625	438.08	12-FL T5 28 W	12-FL T5 28 W
$Library_3$	5.7	3	2.5	267.1	327.08	4-FL T5 28 W	4-FL T5 28 W
207	10.7	8.5	2.5	281.61	420.8	20-FL T5 28 W	20-FL T5 28 W
208	8.55	8.5	2.5	308.68	409.61	16-FL T5 28 W	16-FL T5 28 W
209	8.55	8.5	2.5	312.04	409.61	16-FL T5 28 W	16-FL T5 28 W
210	8.55	8.5	2.5	227.04	409.61	16-FL T5 28 W	16-FL T5 28 W
211	8.55	8.5	2.5	305.04	409.61	16-FL T5 28 W	16-FL T5 28 W
212	12	8.5	2.5	212.36	379.93	20-FL T5 28 W	20-FL T5 28 W
213	12	8.5	2.5	310	379.93	20-FL T5 28 W	20-FL T5 28 W
Stentorian	4.15	4.6	2.5	258.44	307.49	2-LED T8 20 W	4-FL T5 28 W
214	12.2	8.5	2.5	198.5	373.7	20-FL T5 28 W	20-FL T5 28 W
215	11.4	9.03	2.5	204	301.16	16-FL T5 28 W	16-FL T5 28 W
217	8.5	11.4	2.5	210.8	394.96	18-FL T5 28 W	20-FL T5 28 W

Table 4. Required illuminance of the rooms in the Aguinaldo Hall

Location/ Area	Length (m)	Width (m)	Height (m)	Actual average illuminance (lux)	Required illuminance (lux)	Installed lamps (Type/Watts)	Proposed lamps (Type/Watts)
101	5.7	6.7	3	172.625	403.75	9-FL T8 36 W	11-FL T5 28 W
102	5.7	6.7	3	105.8125	403.75	9-FL T8 36 W	11-FL T5 28 W
EE/ECE Faculty	5.7	6.7	3	273.625	403.75	9-FL T8 28 W	11-FL T5 28 W
Dean's Office	5.7	6.7	3	299	403.63	8-FL T8 36 W 7-FL T5 28 W	11-FL T5 28 W
CET R&E Office	3.2	3.4	3	82	330.25	2-FL T8 36 W	4-FL T5 28 W
CE Faculty	5.7	6.7	3	261.1875	403.75	9-FL T8 36 W	11-FL T5 28 W
Accreditation	5.7	6.7	3	267.125	403.75	9-FL T8 36 W	11-FL T5 28 W
ME/IE Faculty	5.7	6.7	3	296.4375	403.75	9-FL T8 36 W	11-FL T5 28 W
204	4.1	3.2	3	118.81	348.18	4-FL T5 28 W	5-FL T5 28 W
206	5.7	6.7	3	227.3125	403.75	9-FL T5 28 W	11-FL T5 28 W
207	5.7	6.7	3	186.375	403.75	7-FL T5 28 W 2-FL T5 36 W	11-FL T5 28 W
Hallway 1^{st}	24.7	2.4	3	101.875	106.52	6-FL T5 28 W	7-FL T5 28 W
Hallway 2^{nd}	19	2.4	3	73.11	135.31	6-FL T5 28 W	6-FL T5 28 W
Red Cross	3.3	5.8	3	94.22	388.11	2-FL T5 28 W	5-FL T5 28 W

3.3.2. Room temperatures

First and foremost, the electrical system of the building must be checked to ensure proper functioning of the ACUs. A simple automatic door-closer can be installed to prevent heat from coming in. Improvements in the airtightness of air-conditioned rooms are very effective in decreasing energy consumption [36].

Also, the windows in the buildings can be installed with a transparent PVC roll. A study shows that this material is more economical with return period of only two years [37]. For energy-saving opportunities, the rooms mentioned above with temperatures ranging from 23.1 to 24 °C are suggested to increase to at least 25 ºC.

4. CONCLUSION

Data shows that most rooms in the buildings have lower than standard level of illuminance. The researchers suggest looking at the surface reflectance of the objects in the rooms such as walls, furniture, and office equipment. Some rooms in the buildings have hot temperatures the entire day due to issues in the electrical system. It is therefore recommended that, apart from re-checking the efficiency of the air-conditioning units, corrective actions should be undertaken to correct the electrical system. As an initial step, automatic door closers and PVC roll curtains/blinds must be installed to prevent heat from coming in the rooms, but further study is needed to also check the airtightness of the buildings.

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