Indicative Saving of Up To 70% with Inverter R-32 Replacement Room ACs at The Bank of Africa

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Report of the Bank of Africa Pilot Project Team[1]

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Summary for Policymakers

In 2019, the Government of Morocco with industry and non-governmental partners organized the Morocco Banker's Air Conditioner (AC) Buyers Club with an ambition to gain access at a competitive and affordable cost to room air conditioners (RACs) with high-efficiency and low global warming potential (GWP) refrigerants as mandated globally by the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol). The Morocco Banker's AC Buyers Club and affiliates discovered that the inventory of installed RACs in Morocco: 1) has incredibly low nameplate energy efficiency, 2) depends on obsolete ozone-depleting greenhouse gas (GHG) R-22 (100% hydrochlorofluorocarbon – HCFC-22) with some obsolete ozone-safe R-410A (50%/50% blend of hydrofluorocarbon—HFC-32 and HFC-125) systems, 3) was improperly installed with clustering and stacking of condensers and poor air circulation, and 4) was infrequently maintained for energy efficiency. Besides, it was determined that the heat island temperatures in Moroccan cities are much higher than at the official weather stations that are located away from human activity and that electric generation from fossil fuels is less efficient and transmission and distribution losses far higher than previously appreciated, which has an impact on the carbon intensity of electricity at the point of use, particularly during peak cooling periods when the least efficient power plants are put into operation.

In response to these findings the Government of Morocco and the Morocco Banker's AC Buyers Club have decided to replace older RACs with next-generation technology using more climate-friendly refrigerants. To accomplish this objective, the partnership:

- Developed and published a new metric for life cycle AC carbon footprint taking into account electricity generation, transmission, and distribution at high ambient temperature; urban heat islands and stacking and clustering of AC condensers; and the carbon intensity of incremental power at peak and off-peak loads efficiency
- Partnered with Bank of Africa to baseline test two typical RACs installed in two bank branches in Marrakesh, which is one of Morocco's hottest cities.
- Partnered with Bank of Africa and Daikin to test next-generation highly efficient RACs using lower-GWP refrigerants as replacement for the baseline RACs that were baseline tested.

This report provides the indicative finding that the RAC replacement program planned by the Government of Morocco and partners will reduce power consumption by up to 70% with additional economic and climate benefits from the recovery and destruction in local cement kilns of obsolete HCFC and HFC GHG refrigerants.

Power consumption of two old RACs was tested from September 12 to October 30, 2019, at the Bank of Africa's Dar Saada and Bab Doukkala Marrakesh branches. During this two-month data monitoring, annual cooling energy consumption was estimated for Marrakech electricity rates as follows:

- The poorly installed RACs using ozone-depleting GHG refrigerant R-22 with the lowest energy efficiency (coefficient of performance -- COP=2.0) are estimated to annually consume about 1,800 kWh of electricity at a cost of about 2,680 Dirham (US$ 280).
- The properly installed RAC using ozone-depleting GHG refrigerant R-22 with ordinary energy efficiency (COP=2.8) is estimated to consume annually about 1,200 kWh of electricity for at 1,650 Dirham (US$ 170).
- The replacement inverter RAC using ozone-safe climate-friendly next-generation refrigerant R-32 with very high efficiency (COP up to 5.3) is estimated to consume about 650 kWh of electricity annually at a cost of about 790 Dirham (US$ 80).
- The savings is 1,890 Dirham/year (US$200/year) by replacing the poorly installed lowest efficiency AC and 860 Dirham/year (US$90/year) by replacing the lowest efficiency RAC if it was properly installed.
- The savings will be greater for even older RACs that are even less efficient when purchased and improperly installed and badly maintained since the energy efficiency of the mix of installed RACs has generally improved with time.

It should be noted that the current work is based on small and statistically insignificant sample size, the simple monitoring could not take into consideration factors such as the number of door openings and closings, occupancy and changes in air conditioning tastes and preferences, and there was occasionally lost data due to network and interconnection unreliability. Nevertheless, the findings are unequivocal and overwhelmingly convincing that replacement of older, improperly installed, and badly maintained RACs yields extraordinary saving in electricity consumption that helps clean the air, protect health and environment, and increase the quality of life of the people of Morocco when money saved on electricity is spent locally on products and services such as nutrition, health, education, arts, and community.

Summary of Findings of The Bank of Africa AC Monitoring Pilot

The testing of older RACs installed at the Bank of Africa confirmed very low nameplate energy efficiency compared to the next-generation R-32 inverter RACs and confirmed that installation with inadequate air circulation at condensers reduces energy efficiency by 36% or more. The same data logging instruments used in 2019 to determine the baseline power consumption were used to collect for the indoor and outdoor temperatures and power consumption of two new RAC units from September 5 to September 25, 2020, at the Dar Saada branch. Data shows that with the new RAC, the room temperature was set about 3.4°C higher in 2020 than in 2019, possibly because the new AC provided greater comfort with occupant-directed air distribution made possible by the occupant sensors in the new RACs. The daytime average usage ratio in 2020 was at 60% to 91% of that in 2019. New RAC Unit (#E2-2) consumed 70% to 90% less power than the old RAC Unit (#B2-1). When the daily energy consumption of the new RAC Unit (#E2-2) is compared with the old RAC Unit (#B2-2) as two units had a similar daytime average usage ratio at around 20%, the new RAC Unit (#E2-2) consumed only 31.5% power consumption in daily basis.

The Morocco findings are comparable to the coordinated work with the Brazil Manufacturer's Buyers Club that demonstrated up to 70% savings of new R-32 inverter RACs compared to older RACs with motors operated at single-speed and with improperly installed condensers. However, the 2020 field measurement was delayed and hindered by the COVID-19 regulations and small sample size. The Morocco Banker's Buyers Club project will continue to measure and will extrapolate these findings to the scenario of replacing 4.3 million older RACs in Morocco with recovery and destruction in local cement kilns of obsolete ozone-depleting and GHG refrigerants from the old equipment and with components and materials recycled to conserve natural resources and provide local employment and with the advantage that old equipment will never be redeployed.

***Baseline RAC Testing Confirmed**:*

- Very low nameplate energy efficiency compared to the next-generation RACs
- Old single-speed RACs using ozone-depleting GHG R-22 with COPs of only 2.0 to 2.8. Note that equipment in less prosperous enterprises and homes will likely be even lower in nameplate efficiency and more likely to be improperly installed.
- Installation with inadequate air circulation at condensers consumes 36% or more energy.
- Even higher efficiency of the new equipment will be realized by relocating condensers to favorable locations away from direct sunlight and poor air circulation while minimizing connecting tube lengths for efficiency and charge minimization.

Replacement RAC Testing Confirmed:

- Old single-speed low-efficiency R-22 RACs were replaced with next-generation inverter RACs using ozone-safe, climate-friendly R-32 with COPs of 3.1 to 5.3 (Indian Seasonal Energy Efficiency Ratio – ISEER = 5.8).

- Replacement RACs were expertly installed for the highest possible energy efficiency and lowest possible carbon footprint.
- Outdoor units were installed at favorable locations away from direct sunlight and mounted for unobstructed cooling air circulation and to minimize connecting tube lengths for efficiency and charge minimization.
- Replacement of older RACs with the properly installed Inverter R-32 high-efficiency RACs or equivalent is expected to reduce RAC sector national energy consumption and carbon footprint by well over 46%.

Table: Energy Consumption and Utility Bill Estimated for Marrakech, MO

Installation Case	**Poorly Installed**	**Properly Installed**	**Properly Installed**
Compressor Type	Non-Inverter	Non-Inverter	Inverter
Refrigerant Type	R-22	R-22	R-32
COP	2.0	2.8	5.8 (3.1 – 5.3)
Cooling Energy Consumption [kWh]	1,796	1,194	646
Energy Savings [%]	-50	0	46
Utility Bill [MD]	2,681	1,654	787
Utility Savings [%]*	-62	0	52

1. Introduction to the Montreal Protocol Phaseout of Ozone Depleting Substances (ODS) and Phasedown of Ozone-Save Hydrofluorocarbon (HFC) Greenhouse Gases (GHGs)

In 1986, the Montreal Protocol was signed and since then has become the most successful environmental treaty with every United Nations state a Party, every Party normally in compliance, and nearing completion of the phaseout in production and consumption of controlled ODSs. Because most ODSs are also powerful GHGs, the Montreal Protocol also protected climate.

In 2016, 197 countries adopted in Kigali Rwanda an Amendment to the Montreal Protocol that will phase down the production and consumption of HFCs that were once necessary to rapidly protect the ozone layer, but are no longer needed because more affordable and environmentally superior technology has been commercialized or will soon be commercialized (UNEP, 2016).

Developed countries shifted from R-22 to R-410A in room air conditioners (RACs) and are now rapidly shifting overwhelmingly to R-32. Developing countries are mostly still using R-22 with single-speed motors, but have the opportunity to leapfrog obsolete R-410A and move directly to R-290 and R-32 inverter RACs if they can overcome environmental dumping and gain access at affordable cost.[2]

Under the Kigali Amendment, countries are committed to phasing down the production and consumption of HFCs by more than 80 percent over the next 30 years. Figure 1 shows the global HFC phase down schedule (EERE, 2019). According to this schedule, HFC emissions will be phased down by two-thirds in developed countries by 2029 and by 2044 for developing nations. The European Union (EU) regulation is somewhat faster schedule with two-thirds phasedown by 2024 (2020). The HFC phase down will ultimately reach the 80% to 85% reduction range unless strengthened by an Adjustment to the Montreal Protocol, which is typical as technology is commercialized and becomes affordable through competition and full economy of scale. The United States recently enacted the *American Innovation and Manufacturing Act of 2020*, which provides federal authority to phase down HFC production and consumption in line with the Kigali Amendment. The law mandates a reduction of HFCs by 85% over the next 15 years, and provides the US EPA with the authority to regulate HFCs even faster in key sectors.

[2] In India, Godrej & Boyce (Godrej) sells a range of R-290 RACs with installation included in the price. The Godrej technicians are specially trained in safe practices for the installation and service of RACs using highly flammable refrigerants. The total cumulative sales to date by Godrej is likely greater than in the rest of the world combined. In China, projects with German partners have converted some production lines to be capable of producing R-290 RAC, but there are no regular domestic sales. (For example, see: http://multilateralfund.org/Our%20Work/DemonProject/Document%20Library/FactSheet%20R290%20Room%20AC.pdf.) Chinese manufacturer Midea – the only room AC to earn Germany's "Blue Angel" ecolabel – announced plans to market a small R-290 RAC in the EU (https://accelerate24.news/regions/europe/highly-rated-midea-r290-room-ac-expected-in-germany-this-year/2020/), but it is not yet available. In the United Kingdom (UK), one RAC R-290 model is offered for do-it-yourself (DIY) installation (https://www.coolingpost.com/uk-news/sales-of-r290-splits-to-diyers-is-irresponsible/).

Parties to the Montreal Protocol are likely to offer early financing and to accelerate the HFC phasedown schedule because:

1. Faster action is needed to avoid polar climate tipping points;
2. Environmentally superior technology is available or soon to be available;
3. It is less expensive to leap-frog HFC-410A and transition to next-generation RACs than to make a first transition from HCFC-22 to HFC-410A and then a second transition from HFC-410A to the next generation technology; and
4. Developing countries are anxious to avoid obsolete R-410A equipment being dumped into their markets that will be expensive to maintain as refrigerant becomes scarce under the phasedown.

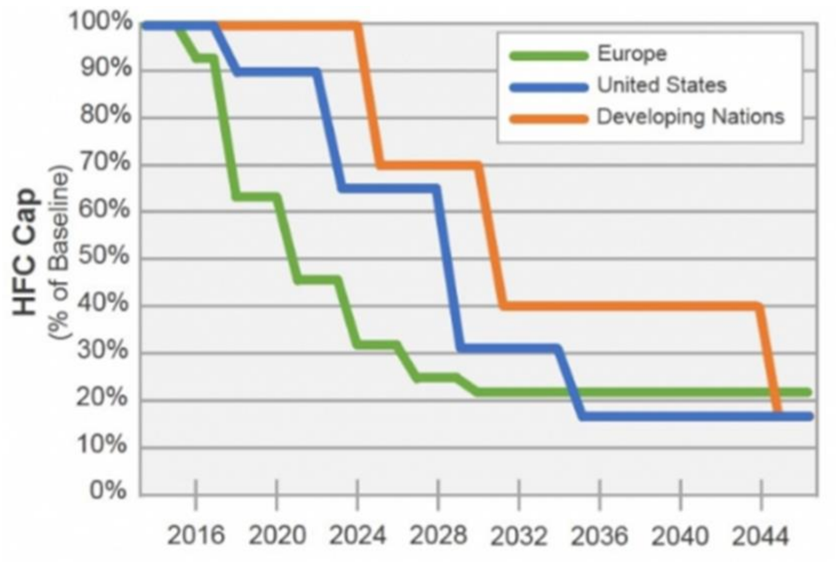


Figure 1: Global HFC Phase Down Schedule

2. The Morocco Banker's Air Conditioner Buyers Club

The Government of Morocco is partnering with Moroccan banks and international non-governmental organizations (NGOs) with high ambitions to transform the local markets to affordable next-generation RACs with the lowest life cycle footprint and to leverage that national leadership to all of Africa (Andersen et al., 2020).

3. Objectives of the Bank of Africa Energy Efficiency Monitoring Pilot

The Morocco Bank of Africa pilot demonstrates how developing countries can leapfrog from the ozone-depleting and high-global warming potential (GWP) refrigerant R-22 and ozone-safe high-GWP R-410A single-speed RACs to the non-ozone depleting and low-GWP R-32 inverter RACs in new sales and the replacement of older RACs. Part of that project is the field testing of existing equipment and high-efficiency replacement at representative sites in Morocco so that the same approach of leapfrogging R-22 and replacing older RACs can be expanded to all of Morocco and all African counties.

4. Field Test Sites Selection and Baseline Systems

The Bank of Africa offered four of its branches as test sites in Marrakech, Morocco: Route de Casa (#1), Dar Saada (#2), Bab Doukkala (#3), and El Massira Iziki (#4). Figures 2 and 3 show how the indoor and outdoor units of RACs were installed in those four sites recommended. After collecting relevant information on test sites and their baseline RAC systems, the team came to the following conclusions and observations:

RAC Sizing:

- The RAC in branch #1 was oversized.
- The RACs in branch #2 (Dar Saada) and branch #3 (Bab Doukkala) were sized properly.
- The RACs in branch #4 were undersized or the building needs to be better insulated.

Figure 2: Picture of Buildings Recommended for Field Testing

(a) Branch #1 (Left: Front View; Right: Front Right Corner View

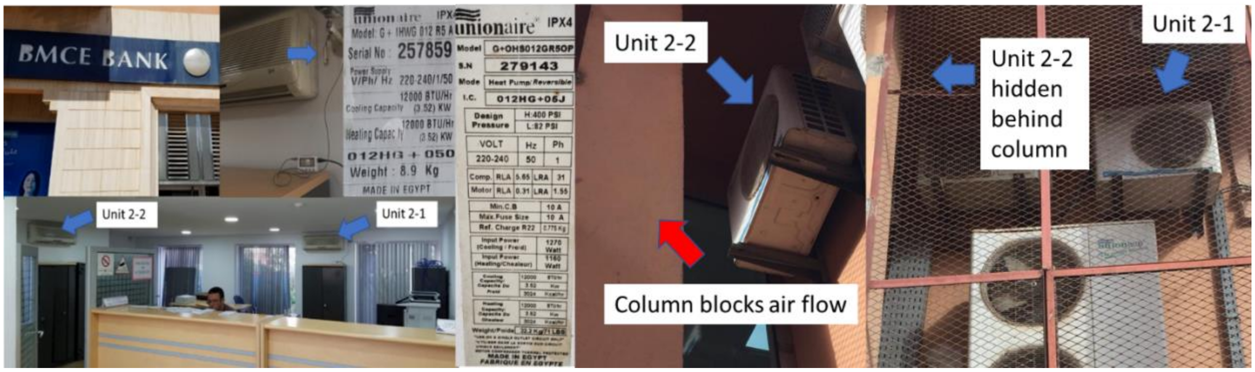
(b) Dar Saada (#2) (Left: Front Right Corner View, Right: Back Left Corner View)

(c) Bab Doukkala (#3) (Front Right Corner View, Right: Back Right Corner View)

(d) Branch #4 (Front Right Corner View, Right: Back View)

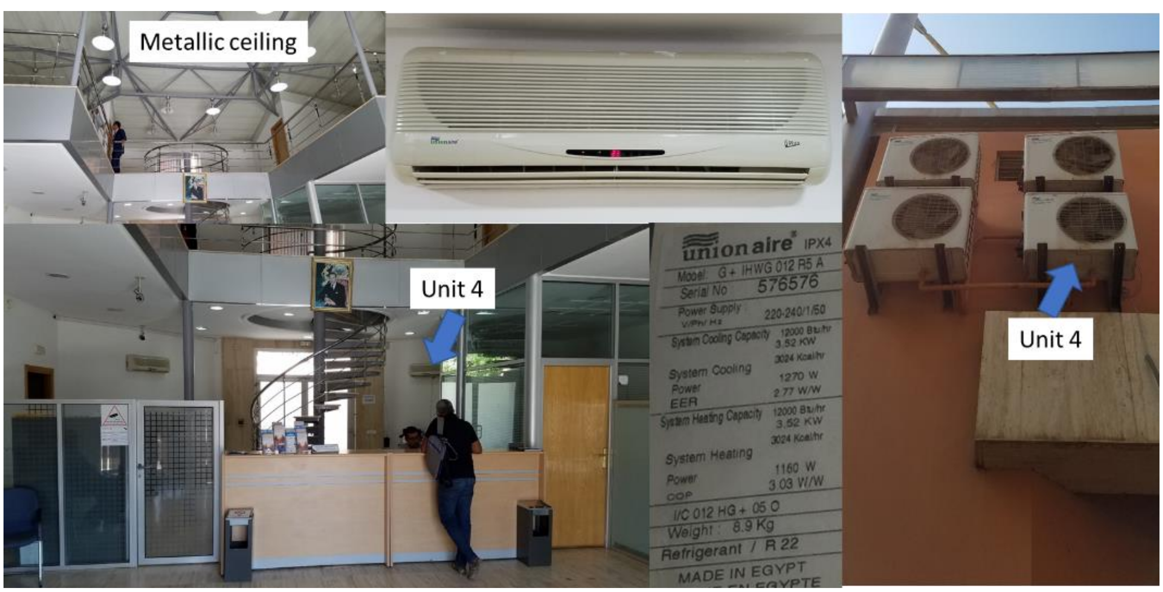
Figure 3: RACs Installed in Four Marrakech Branches of Bank of Africa

(a): RAC in Branch #1



(b) RAC in Dar Saada (#2)

(c): RAC in Bab Doukkala (#3)



(d): RAC in Branch #4

Improper Installation of the Condensers Unnecessarily Increases Energy Use:

- Branch #1 outdoor unit (ODU—inverter, motor, compressor, and condenser) is located within a C-shape balcony, which results in higher inlet temperature due to poor air circulation around the condenser.
- Dar Saada Branch (#2) and branch #4 ODUs are installed in a stacked pattern with other ODUs, which results in higher inlet temperature due to poor air circulation around the condensers.
- Dar Saada Branch (#2) ODU is facing east while other branches are facing west.
- All but one ODU was installed with less than 30 cm backspacing, which restricts air circulation around the condensers, which increases energy use.
- Bab Doukkala Branch (#3) has a higher line voltage at 230V while other branches are at 220V.

Baseline RACs Installed

Dar Saada (#2) and Bab Doukkala (#3) Branches were selected as baseline test sites for this project. Table 1 shows test site information for branches #2 and #3. Table 2 shows the specifications of RACs used in branches #2 and #3. These baseline RACs are all using R-22 as their refrigerant and single-speed compressor, and their COPs are only 2.54 to 2.77. This means that these units are not only inefficient but also environmentally harmful so that they can be economically replaced with more energy- efficient and lower-GWP RACs.

Table 1: Baseline Test Sites at Branches #2 and #3

Test Site Branch No.	Branch # 2	Branch # 3
Branch in Marrakech	Dar Saada	Bab Doukkala
Room Size (WxDxH) [m]	7.2x5.7x2.1	4.1x4.8x7.3
Room Volume [m^3]	86.2	45.3
Room Type	Partially open counter	Enclosed manager office
Thermostat Setting [°C]	25	25
Line Voltage [V]	220	231
IDU Location; Unit Combination	1^{st} F; Two-3.5 kW	1^{st} F; One unit
RAC ODU Environment	In semi-open space; On wall	On wall
ODU Facing	East	West
Office floor in Building	Ground floor in four-story building	Ground floor in six-story building
Volumetric Capacity [W/m^3]	81.6	77.7
Sizing	Normal	Normal

Table 2: Specifications of RACs at Test Sites
at Dar Saada (#2) and Bab Doukkala (#3)

Branch in Marrakech	**Dar Saada (#2)**	**Bab Doukkala (#3)**
Compressor Type	Non-Inverter	Non-Inverter
Manufacturer	Unionaire	Trane
Indoor Unit Model	G+ IHWG 012 R5A	2MWW0512, AB0R2AA
Outdoor Unit Model	G+ OH9012	2TWK0512, AB002AA
Capacity (Cool/Heat) [W]	3,517/3,517	3,517/3,517
Input [W]	1,270/1,160	1,340/1,240
Current [A]	5.8/5.3	6.1/5.7
COP	2.77/3.03	2.62/2.84
Power Supply [V/Ph/Hz]	220-240/1/50	220-240/1/50
Refrigerant Type	R-22	R-22
Refrigerant Charge [g]	575	680

Baseline ODUs Installed in Dar Saada (#2) and Bab Doukkala (#3)

Highlights of installation characteristics from the onsite inspection are as follows:

- Unit #B2-1's ODU was installed above other bigger capacity ODU where it would experience hotter temperatures from heat rising. In addition, it was improperly installed close to the wall with poor air circulation.
- Unit #B2-2's ODU front side was blocked by the building column. Moreover, this Unit #B2-2 had about double the connecting tube length compared to Unit #B2-1, which causes an energy penalty.
- Unit #B3's ODU was installed on the backside of the building without any obstructions.
- Other RAC ODUs were installed above Unit #B3 so that they would experience hotter temperatures from heat rising and units were also improperly installed too close to the wall.

5. Instrumentation

To compare the field performance of existing inefficient R-22 single-speed RACs and high-efficient R-32 inverter RACs under the same operating conditions in the same building, instruments were selected that are typically used for residential temperature and power measurements with automatic online data uploading capability to the cloud. Table 4 lists the instruments used in the field testing. Instruments were connected according to the overall wiring diagram shown in Figure 4. The Eyedro Power Meter (2019) was selected and calibrated for the power monitoring. As shown, power meters and routers were powered through the uninterruptable power supply (UPS) for continuous measurement without interruption from power failure. It should be noted that T&RH sensors (2019) were powered through local batteries.

Table 4: List of Instruments Used in the Field Testing

Item	Brand, Model no.
Ethernet Humidity & Temp. Data Logger	T&D, TR-72NW-S
Ethernet Temperature Data Logger w/ 2 External Sensors	T&D, TR-71NW
3m Sensor Extension Cable	T&D, TR-1C30
Wall Mount Bracket	T&D, TR-07K2
Mini-USB to USB 2.0 Cable, 15 ft Length	Cable Matters, Type A/Mini-B
5 Port Gigabit PoE+ Switch (4 PoE+ Ports) – 65W – 802.3	BV-Tech 5 port, POE-SW501G
Home Electricity Monitor	Eyedro, EHEM1-LV
30 A Current Sensor	Eyedro, 30 Amp
2,400 W Power Adapter, Universal Adapter with 4 USB Ports	Eleclead, 220V to 110 V
3 Outlet Grounded Wall Tap Adapter, Power Outlet Splitter	Maximm, 3 outlets, 3 packs
Ethernet Patch Internet Cable, 14 ft	Amazonbasic, RJ45 Cat-6-14 ft
Cat 6 Ethernet Cable, 100 ft Flat White	Jadaol, Cat 6 Ethernet Cable
Interactive Line UPS 865 W/1500 VA	APC, Pro1500, 230V, 50/60 Hz
Wi-Fi Internet Router (Local rental)	Box Fixe Orange, B612s-25d

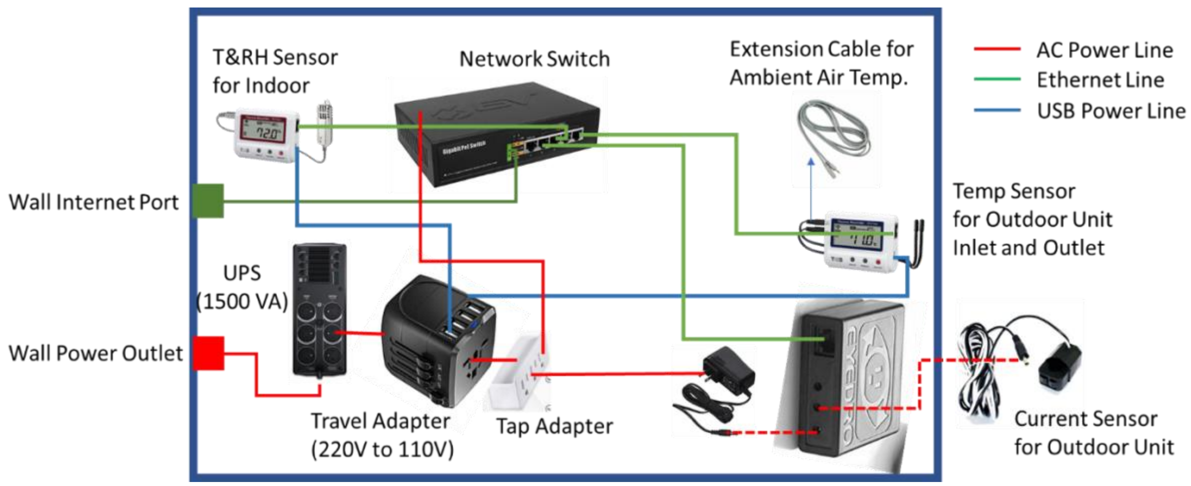
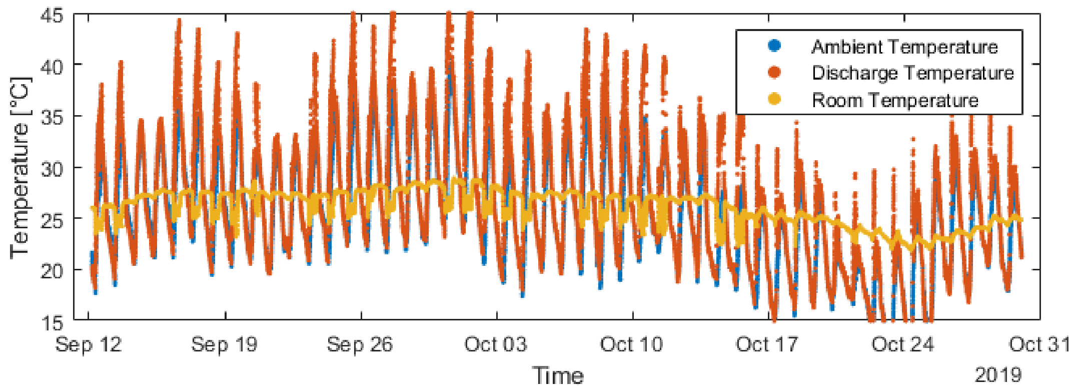


Figure 4: Overall Wiring Diagram

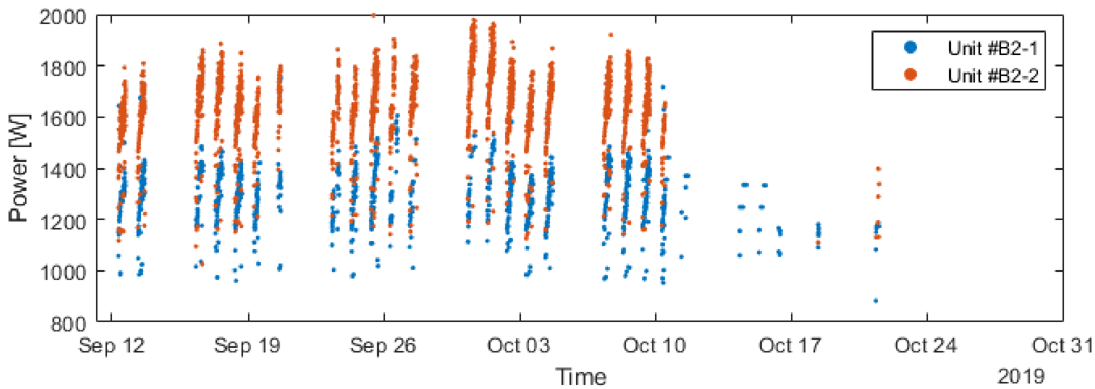
6. Baseline Experimental Data and Data Analysis

Test data collected from September 12 to October 30, 2019, for two RAC units in Dar Saada (Unit #B2-1 and Unit #B2-2) and one RAC unit in Bab Doukkala (Unit #B3) were analyzed. Indoor temperature and relative humidity and the ODU's inlet and outlet temperatures were measured. The RAC total power consumption was measured. Temperatures and power consumption measured for the Dar Saada and Bab Doukkala Branches from September 12 to October 30, 2019, are shown in Figures 5 and 6, respectively. Highlights of operating characteristics from the measured data are as follows:

- Even in early October 2019, the ambient temperature reached 40°C.
- Unit #B2-2 consumed more power than Unit #B2-1.
- Dar Saada and Bab Doukkala office units were diligently turned off during breaks and when the rooms were unoccupied.
- Overall, Bab Doukkala was less frequently operated than Dar Saada.



(a) Temperature



(b) Power Consumption

Figure 5: Temperatures and Power Consumption Data for Dar Saada

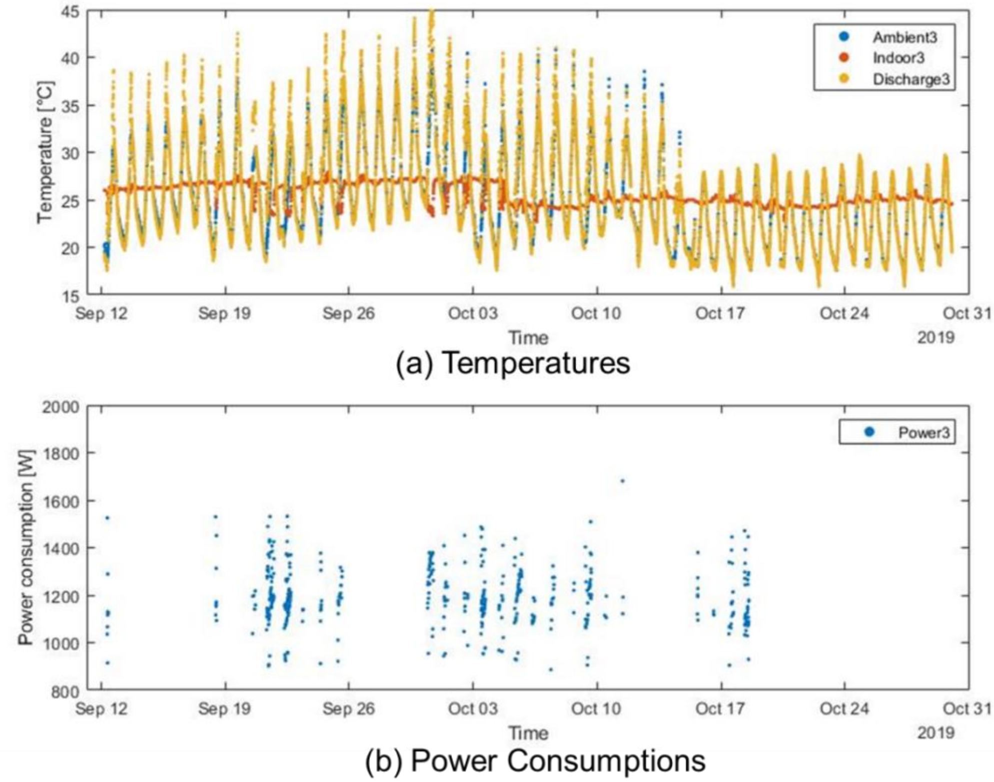


Figure 6: Temperatures and Power Consumption Data for Bab Doukkala

6.1 Daily Average Profiles

To compare the RAC operating behaviors of Dar Saada and Bab Doukkala Branches, the daytime average ambient temperature, daytime usage ratio, and daytime power consumption were averaged on daily basis from September 12 to October 30, 2019 and are shown in Figure 7. Daytime is defined as the RAC's typical operating hours from about 8 am to 6 pm. Moreover, daytime values were averaged for the entire period from September 12 to October 30, 2019, and summarized in Table 7. As can be found from Figure 7 and Table 7, daytime daily averaged temperatures of two branches are about 1.1°C different. The reason is that the ODUs in Dar Saada were installed in a utility cage space on top of a bigger capacity ODU unit while the ODU in Bab Doukkala was installed on a wall without adjacent ODUs and with good air circulation. The daytime usage ratio is defined as the unit's on-time ratio during office hours. As shown, two units in Dar Saada were operated at 33.6% and 22%, respectively, while one unit in Bab Doukkala was operated during only 12.7% of the daytime. The daytime average power consumption of Unit #B2-1 was highest at 369.9 W, and followed by Unit #B2-2 at 183.7 W and Unit #B3 at 149.6 W. Total energy consumption from September 12 to October 30, 2019 were 168,160, 87,889 and 57,717 Wh for Units #B2-1, #B2-2 and #B3, respectively. Actual AC working days during this period were 27, 22, and 24 days for Units #B2-1, #B2-2, and #B3, respectively. Daily energy consumption in this period were then 6,228, 3,995 and 2,404 Wh/day for Units #B2-1, #B2-2 and #B3, respectively. These trends are also related to their power consumption and usage ratios.

Table 7: Daytime Values Averaged for Entire Period from Sep. 12 to Oct. 30, 2019

Unit No.	Daytime Average Ambient Temp. [°C]	Daytime Average Usage Ratio [-]	Daytime Average Power [W]	Total Energy Consumption [Wh]	AC Working Days [Day]	Daily Energy Consumption [Wh/Day]
#B2-1	26.7	33.6%	369.9	168,161.0	27	6,228.2
#B2-2	26.7	22.0%	183.7	87,889.3	22	3,995.0
#B3	25.6	12.7%	149.6	57,716.6	24	2,404.9

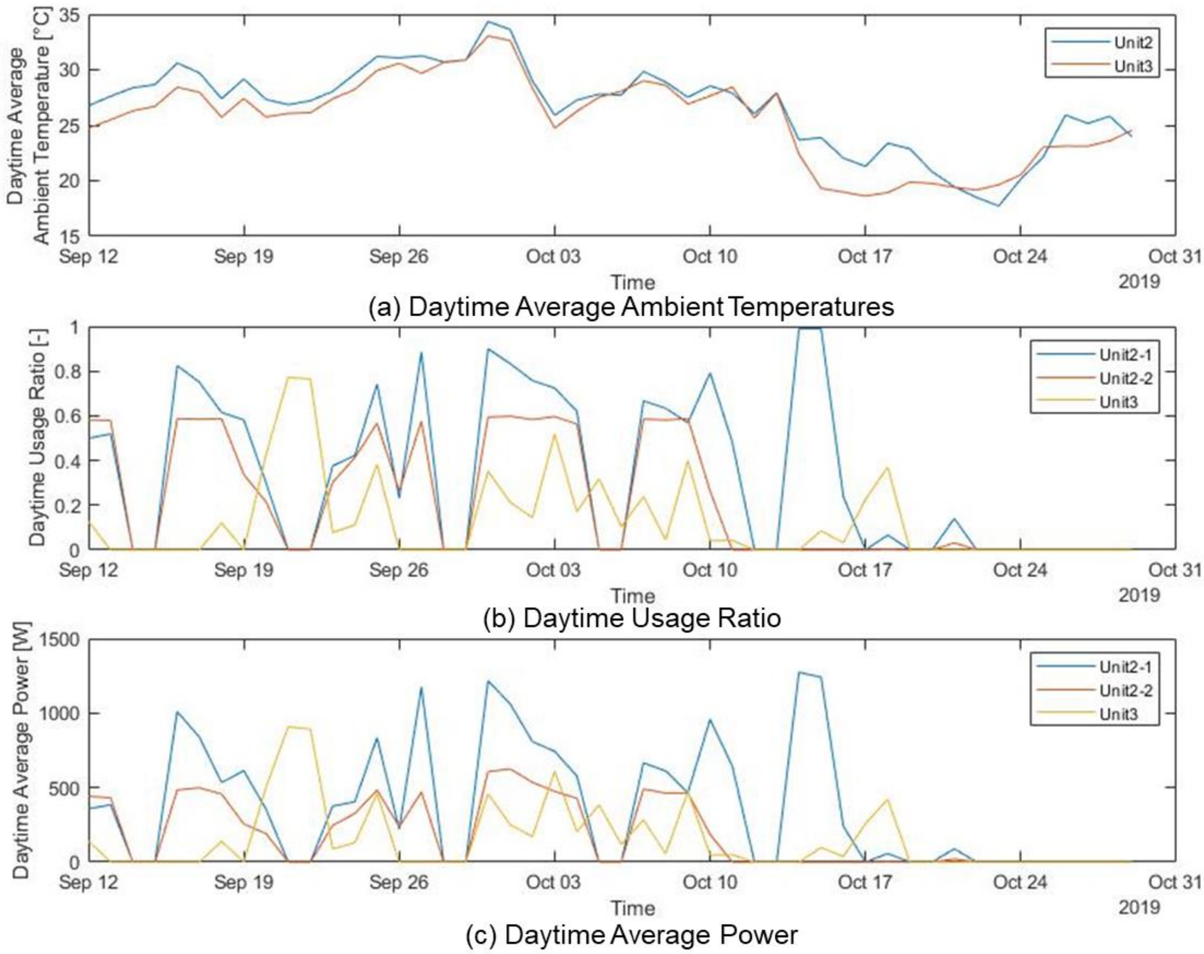


Figure 7: Daily Average Profiles (September 12 - October 30, 2019Error! Hyperlink reference not valid.)

To determine the relationship between the daily average temperature and daily energy consumption, the daily average energy consumption of two units in the Dar Saada is provided for the daily average temperature in Figure 8. While the power consumption of Unit #B2-2 was higher than Unit #B 2-1, the energy consumption of Unit #B2-1 was rather higher than Unit #B2-2. This is because Unit #B2-1 has a higher usage ratio than Unit #B2-2. The energy consumption of both units was increased with ambient temperature. This means that while two identical units were used for conditioning the same space, their usage rate was not the same due to either a slight difference in local return air temperature or by the user control.

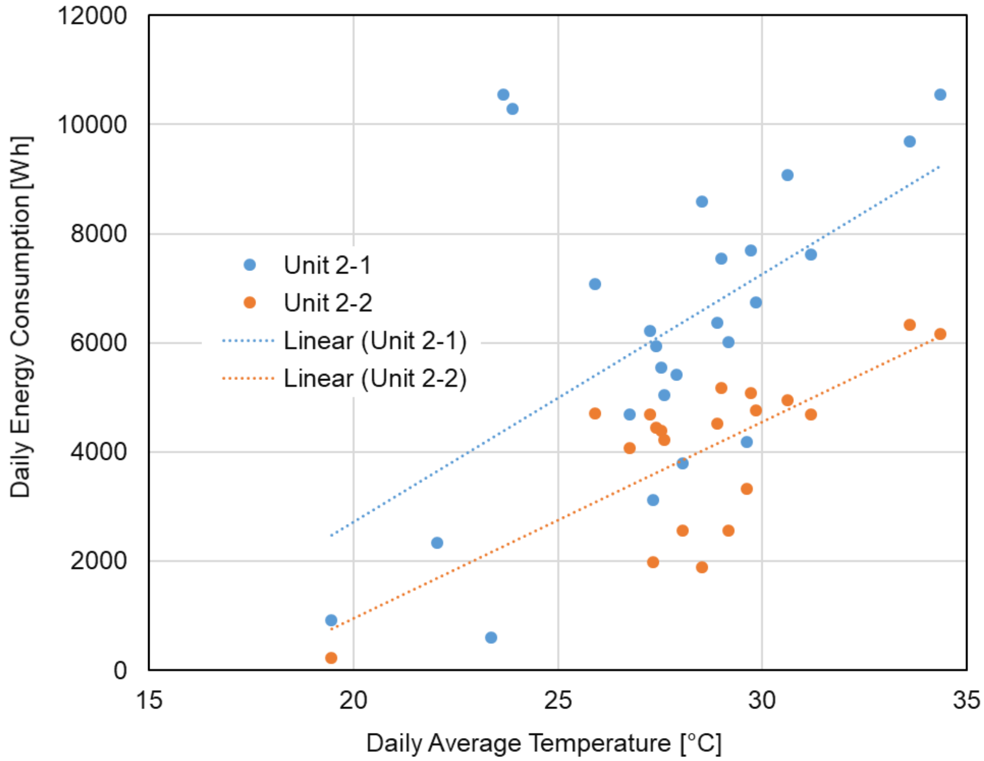


Figure 8: Daily Energy Consumption Versus Daily Average Temperature

6.2 Data Analysis for A Specific Day

To understand how RAC units were operated during a typical day in detail, Figure 9 shows the power consumption profiles on October 17, 2019. From the measured data, the following observations were made for RAC operation hours.

- Unit #B2-1 and Unit #B2-2 were operated from 8 am to 5 pm
- Unit #B3 was operated from 9 am to 2 pm

The difference is due to the purpose of the conditioned spaces. The Dar Saada office was used as a customer counter needing for full-day operation, while the Bab Doukkala office was used as an office for a manager who travels frequently. Figures 10 and 11 compare the room and ambient temperatures, and the power consumption of two branches from 8 am to 5 pm on October 7, 2019. From Figure10, we can notice that the room temperature was maintained at about 25°C and 24°C for the Dar Saada and Bab Doukkala offices, respectively. The ambient temperature at Dar Saada was a few degrees higher than the Bab Doukkala from 10 am to 3 pm but there was a notable temperature increase at around 4 pm on Bab Doukkala. These differences were related to the facing direction of ODUs and their installation environments. The ODUs at Dar Saada were facing east, while the ODU at Bab Doukkala was facing west.

(a) Unit #B2-1

(b) Unit #B2-2

(c) Unit #B3

Figure 9: Power Consumption Profiles on October 17, 2019

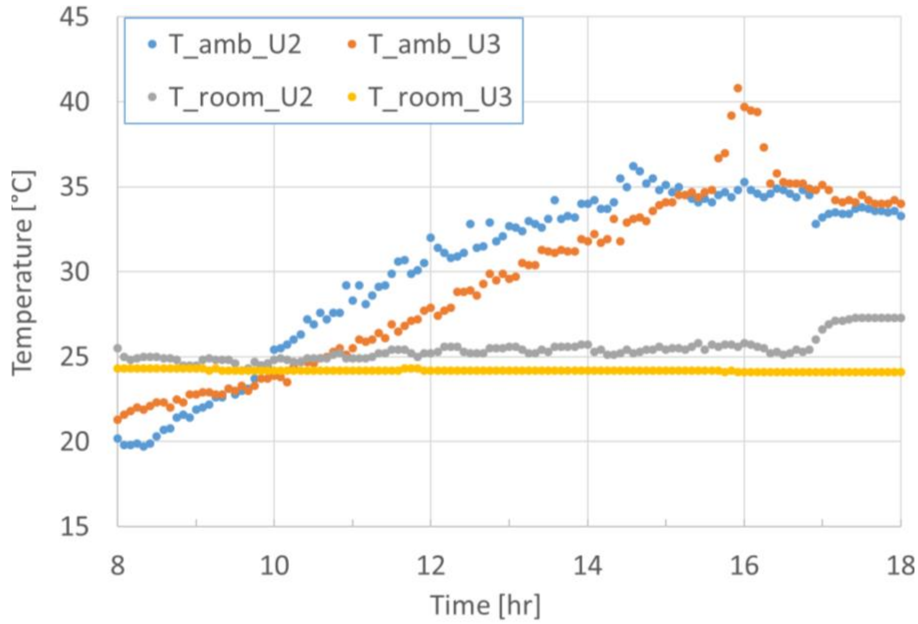


Figure 10: Comparison of Temperature Profiles on October 17, 2019

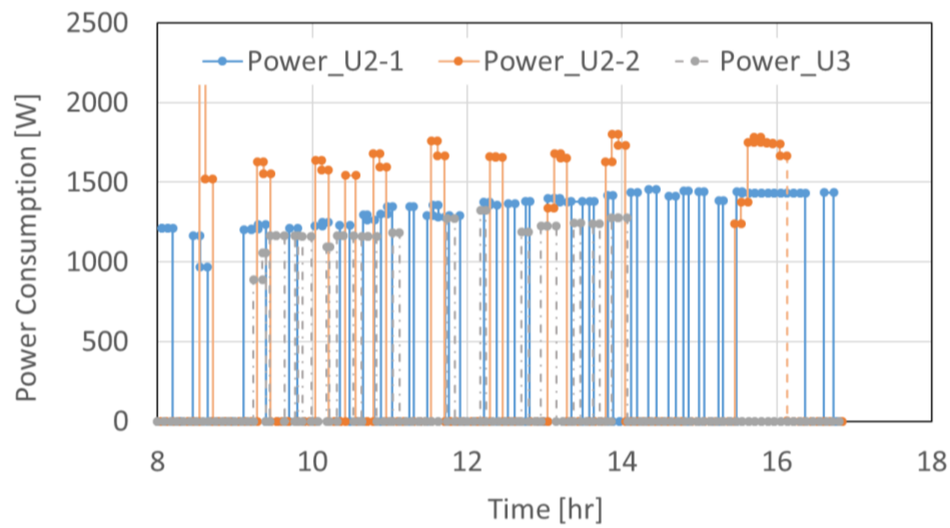


Figure 11: Comparison of Power Consumption Profiles on October 17, 2019

To provide the power consumption and operational difference in a short time period, Figure 12 compares the power consumption of two branches from 9 am to 9:30 am. As shown, the cooling started about 20 minutes late for the Bab Doukkala but the on-time of RAC was longer (like 10 minutes) than the Dar Saada. The on-times of Unit #B2-1 and Unit #B2-2 were about 3 and 2 minutes, respectively. Unit #B2-1 consumed less power than Unit #B2-2.

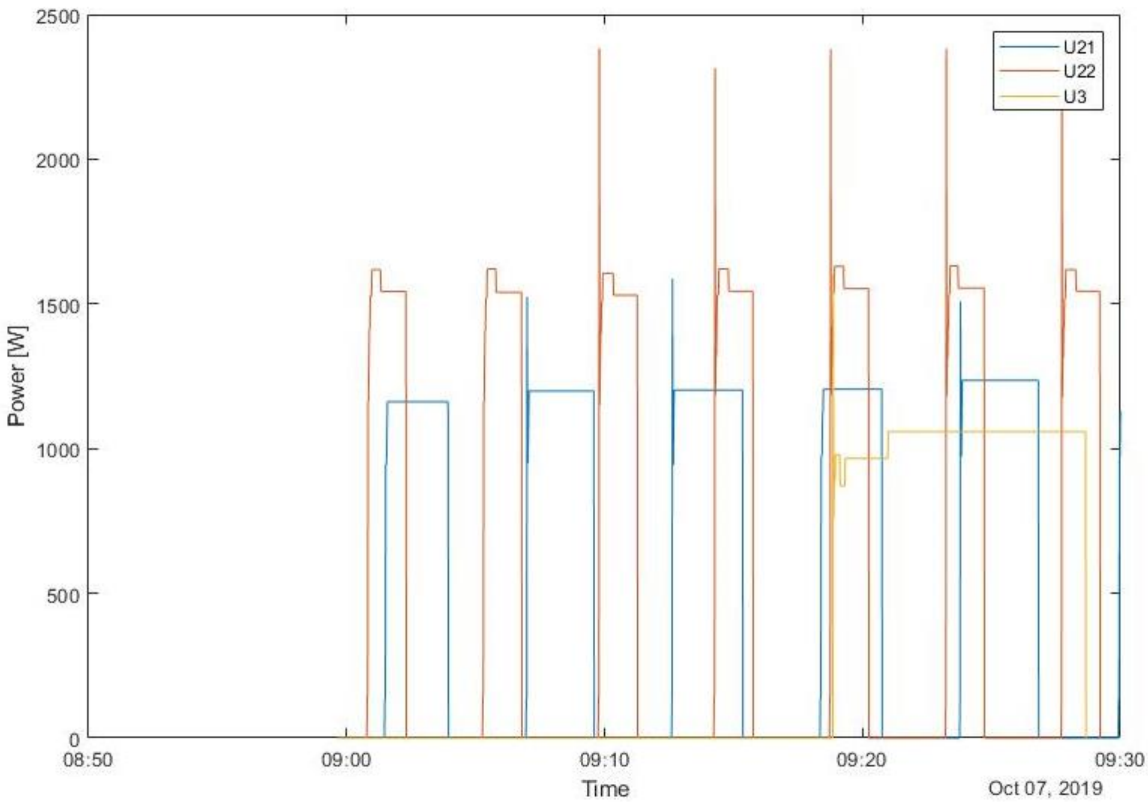


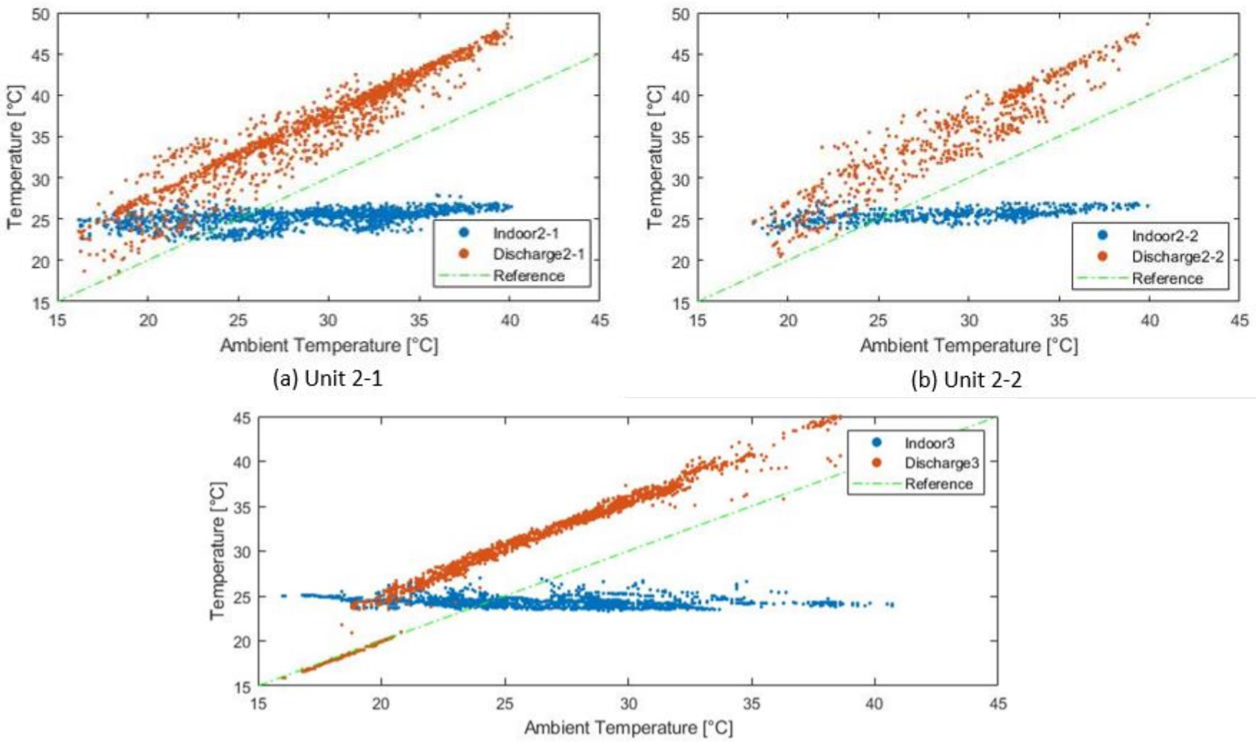
Figure 12: Comparison of Power Consumption from 9 am to 9:30 am on October 17, 2019

6.3 Effects of Ambient Temperature on Discharge Temperature and Power Consumption, and Power Regressions

Figure 13 shows the effect of the ambient temperature on the indoor temperature and discharge temperature of the ODUs. As shown, the indoor temperatures were maintained at about 25°C independent of ambient temperatures. The ODU's discharge air temperatures were 5 to 7°C higher than ambient temperatures. Figure 14 shows the effect of the ambient temperature on power consumption. The cooling started at about 18°C ambient. As ambient temperature increases, so does the power consumption. Then the regression analysis was conducted for power consumption. Table 8 summarizes regression results with fitted equations. As shown in Figure 14, as Unit 3 was much less operated by the user, its power consumption regression was hard to be established with good statistical confidence.

Table 8: Fitted Power Consumption of Test RACs

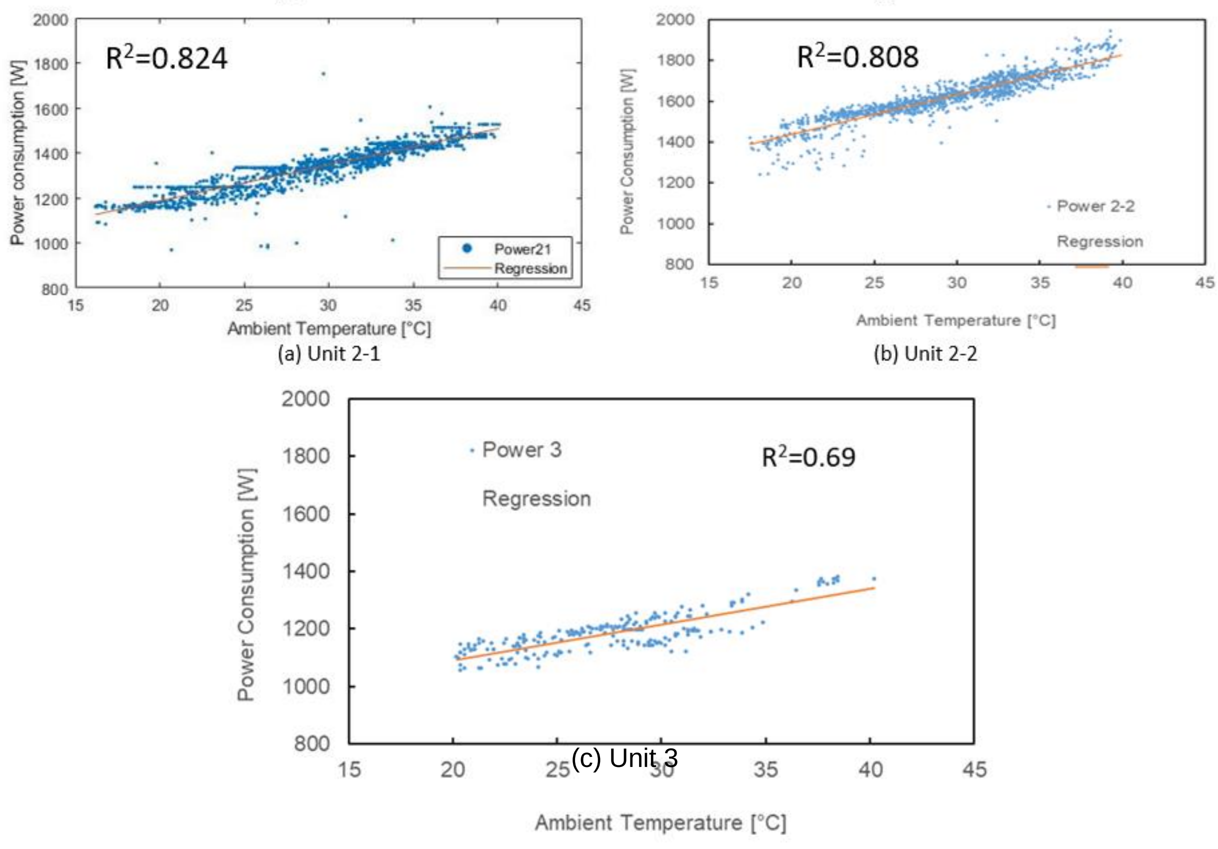
Unit No.	Fitting equation	The coefficient of determination (R^2)
#B2-1	Power = 866.217 + 16.018 * T_{amb}	0.824
#B2-2	Power = 1050.1 + 19.44 * T_{amb}	0.808
#B3	Power = 842.42+12.408* T_{amb}	0.69



(a) Unit 2-1 (b) Unit 2-2

(c) Unit 3

Figure 25: Effects of Ambient Temperature on Space and Discharge Temperature



(a) Unit 2-1 (b) Unit 2-2

(c) Unit 3

Figure 26: Effects of Ambient Temperature on Power Consumption

Table 9 shows the comparison of the manufacturer's rated powers and calculated power consumption. We can deduce the following observations:

- Units #B2-1 and #B2-2: While the same RAC units were used, Unit #B2-1 consumed 12.4% more power, and Unit #B2-2 consumed 36.3% more power than their respective rated powers. These results are due to limited airflow to ODUs and longer pipe length for Unit #B2-2.
- Unit #B3: This unit consumed 4.8% less power than the rated power. This result could be due to low room temperature setting (24.2°C), free airflow, and shaded condition for the outdoor unit.

Table 9: Power Consumption of Test RACs

Unit No.	Rated Power [W]	Measured Power @ 35°C [W]	Deviation [%]
#B2-1	1,270	1,426.8	12.4
#B2-2	1,270	1,730.5	36.3
#B3	1,340	1,276.7	-4.8

6.4 Baseline Measurement Conclusions

Two Bank of Africa branches were selected for detailed data collection and analysis. To compare the field performance of existing R-22 RACs and new R-32 RACs under the same operating conditions in the same buildings, the team selected and installed easily purchased instruments, and collected data for indoor and outdoor temperatures and power consumption from September 12 to October 30, 2019, for the Dar Saada and Bab Doukkala branches. The measured data indicate that the baseline R-22 units consumed -4.8% to +36.3% more power than their respective rated power depending on how IDU and ODU were installed. Unit #B2-2 ODU at Dar Saada was installed improperly at the upper left corner side of the utility cage area where hot air was accumulating from other ODUs so that it consumed 36.3% more power. In terms of the operation time during the office hour from 8 am to 6 pm, two units in Dar Saada were operated in 33.6% and 22% of working hours, respectively, while one unit in Bab Doukkala was operated only 12.7%. Total energy consumption from September 12 to October 30, 2019 were 168,160, 87,889 and 57,717 Wh for Units #B2-1, #B2-2 and #B3, respectively. Daily energy consumption in this period were then 6,228, 3,995 and 2,404 Wh/day for Units #B2-1, #B2-2 and #B3, respectively. The testing of older RACs installed at the Bank of Africa confirmed very low nameplate energy efficiency compared to the next-generation R-32 inverter RACs and confirmed that installation with inadequate air circulation at condensers reduces energy efficiency by 30% or more.

7. Energy Efficient Replacement RACs

To compare the field performance of existing R-22 RACs and new R-32 RACs under the same operating conditions in the same building and typically operated, the team selected the Dar Saada branch as a test site for the new R-32 RACs since the Bab Doukkala branch used the RAC below-average usage due to frequent office vacancy.

7.1 Energy Efficient RAC Selection

For the new energy-efficient RACs, two R-32 RAC units were selected after discussion with the RAC manufacture and branch official, and consideration for environmental impacts. It should be noted that Unit #E2-1 is cooling only RAC, while Unit #E2-2 and baseline RACs (#B2-1 and #B2-2) were heat pumps. Table 10 shows the comparison of specifications of these efficient RACs and the baseline RAC. As shown, both systems have equivalent cooling and heating capacities but new efficient RACs are 14% to 109% and 34% more efficient for cooling and heating, respectively than the baseline RAC. Figure 27 shows indoor and outdoor units of efficient Unit #E2-1. As shown it is rated at a five-star energy efficiency rating.

Table 10: Comparison of Baseline R-22 RACs and Efficient R-32 RACs

System Type	**Baseline RAC**	**Efficient RAC**	
Unit Number	#B2-1 / #B2-2	#E2-1	#E2-2
Type	Heat pump	Cooling only	Heat pump
Compressor Type	Non Inverter	Inverter	Inverter
Manufacturer	Unionaire	Daikin	Daikin
Indoor Unit Model	G+ IHWG 012 R5A	JTKJ35TV16U	FTXF35A
Outdoor Unit Model	G+ OH9012	RKJ35TV16U	RXF35A/B
Cooling			
Capacity (Rated/Min-Max) [W]	3.52	3.62 (1.17 – 4.0)	3.3 (1.3 – 3.8)
Input (Rated/Min-Max) [W]	1,270	822 (220-1,300)	1,000 (290 – 1,300)
COP or Seasonal Energy Efficiency Ratio (SEER)	2.77	5.80	6.21
Heating			
Capacity (Rated/Min-Max) [W]	3.52	-	3.5 (1.3 – 4.8)
Input (Rated/Min-Max) [W]	1,160	-	940 (290 – 1,290)
COP or Seasonal Coefficient of Performance (SCOP)	3.03	-	4.06
Power Supply [V/Ph/Hz]	220-240/1/50	220-240/1/50	220-240/1/50
Refrigerant Type	R-22	R-32	R-32
Refrigerant Charge [g]	575	820	700

Figure 27: Energy Efficient R-32 Test Unit (#E2-1)

7.2 Proper Installation of New RACs

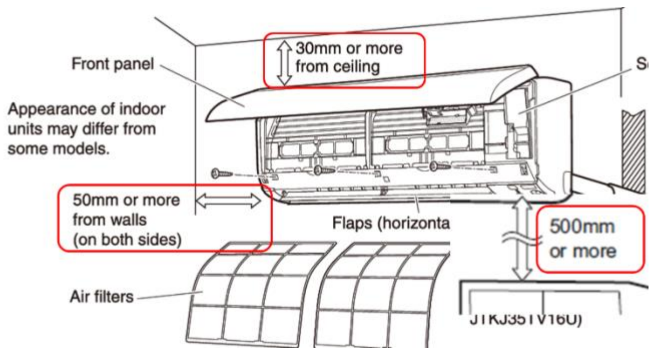
Figure 28 shows the installation guidelines from the manufacture. Local technicians authorized by the manufacturer-installed new RACs according to these guidelines. Moreover, we tried to improve several installation issues of the baseline RACs for the new RAC installations as shown in Figure 29, and details are described next.

7.2.1 Indoor Unit Installation

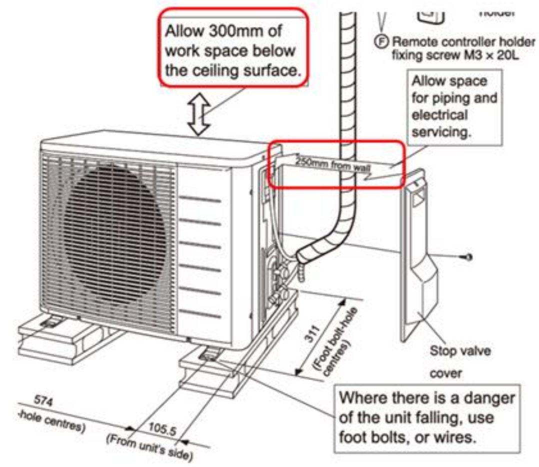
As shown in Figure 28, the manufacture recommends minimum spacing for the top, sides, and bottom of indoor units at 3 cm, 5 cm, and 50 cm, respectively from the wall or any other objects. The old RAC indoor units had less than 3 cm spacing on the top and 50 cm spacing from the cabinet installed just below it (refer to Figure 3). The new RAC indoor units were installed to keep 3 cm spacing on the top and no cabinet below it (refer to Figure 29 (a)). Moreover, the locations of two new RAC indoor units were installed at the north side wall (refer to Figure 29 (a)), while the baseline units were located at the west and north sides (refer to Figure 3). Another reason for the relocation was to minimize the pipe length between the indoor and outdoor units and the refrigerant charge amount.

7.2.1 Outdoor Unit Installation

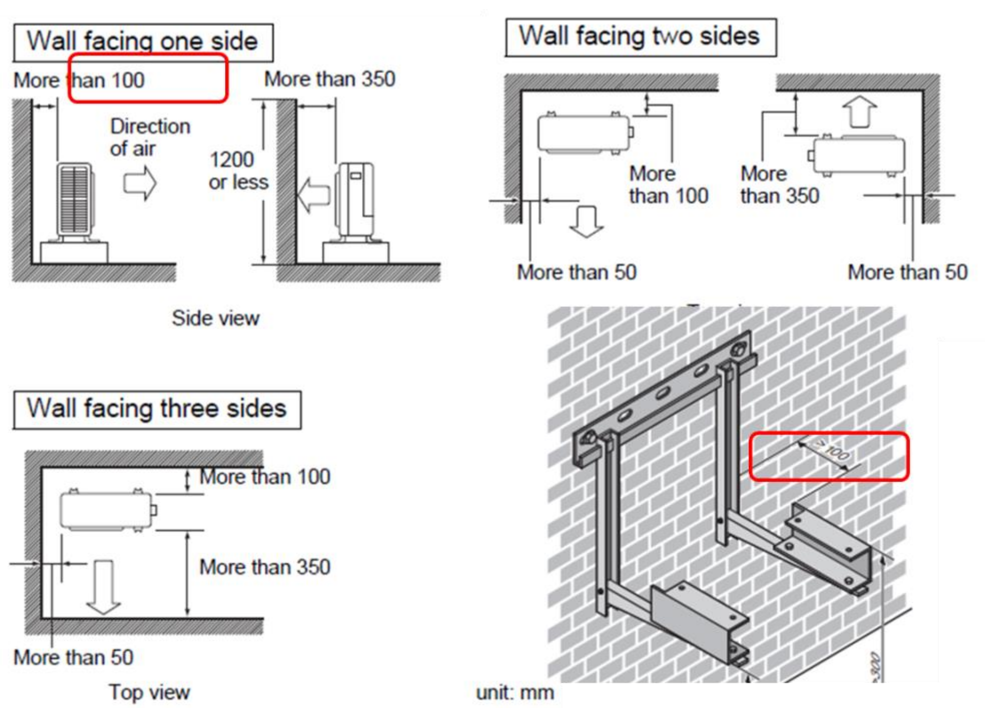
As shown in Figure 28 (b) and (c), the manufacture recommends minimum spacing for the top, sides, and back of outdoor units at 30 cm, 25 cm, and 10 cm, respectively from the wall or any other objects. The old units had less than 10 cm spacing on the back, with other RAC outdoor units installed just below it (refer to Figure 3), and RAC #B2-2 had airflow obstruction in front of it. The new RAC outdoor units were installed to keep 3 cm spacing on the backside without any airflow obstruction. Moreover, the two new RAC outdoor units were placed on the north wall (refer to Figure 29 (b)), while the baseline units were at the east side and without utility cage structure (refer to Figure 3). The main reason for the relocation was to minimize the pipe length between the indoor and outdoor units and avoid any airflow obstruction.



(a) Indoor Unit Installation Guideline

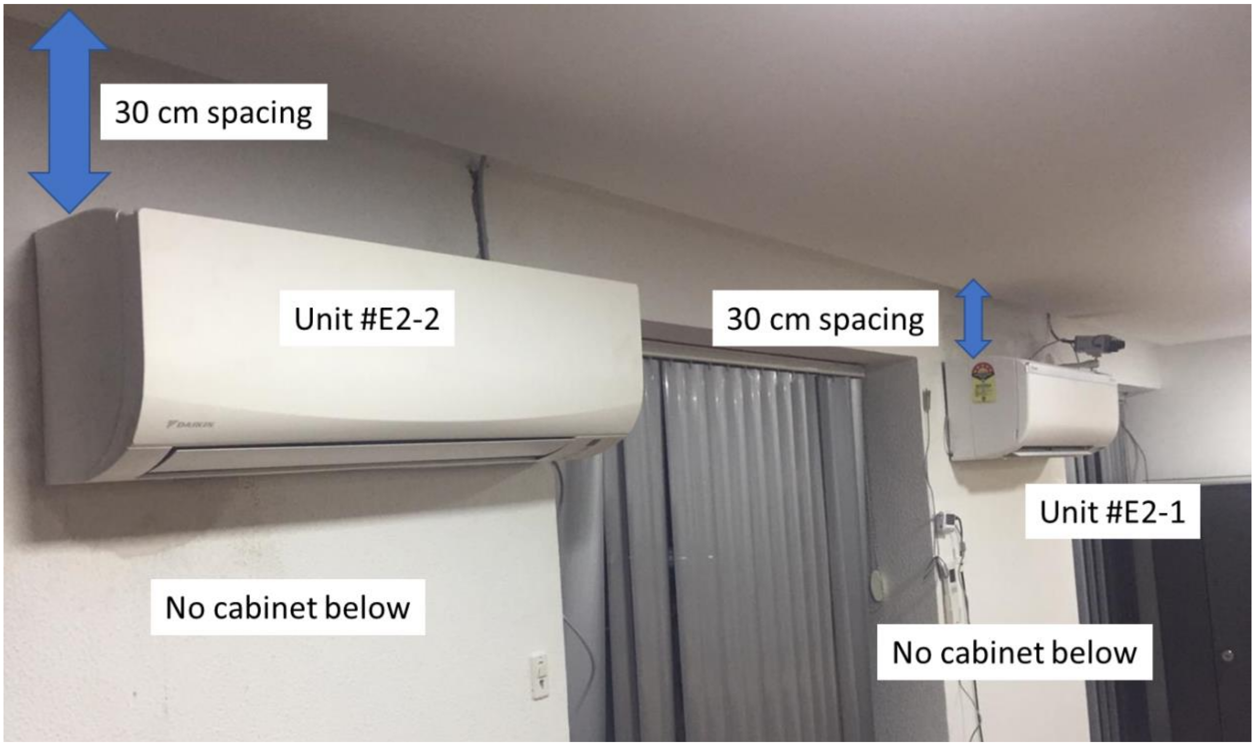


(b) Outdoor Unit Installation Guideline I



(c) Outdoor Unit Installation Guideline II

Figure 28: Installation Guidelines from the Manufacturer



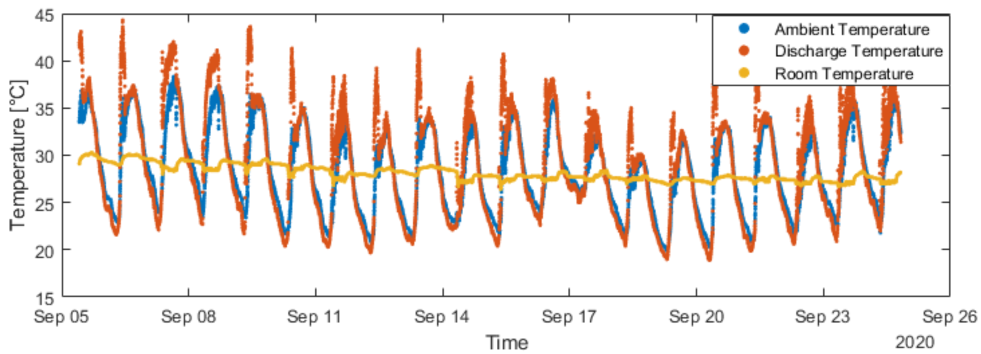
(a) New RAC Indoor Units Installation

(b) New RAC Outdoor Units Installation

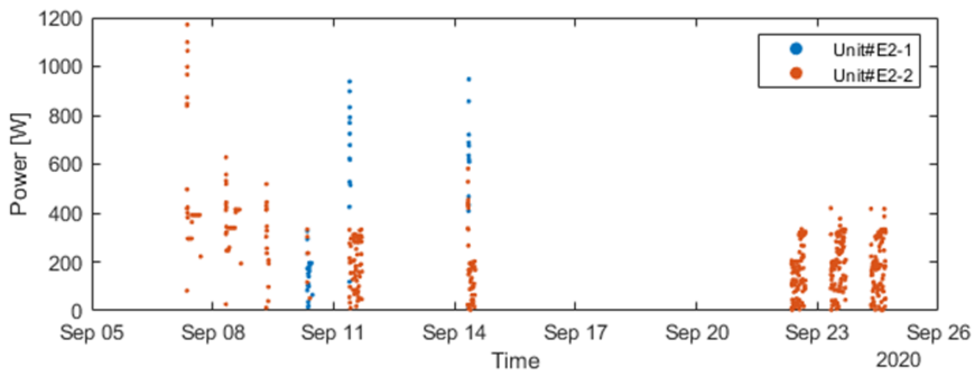
Figure 29: New RAC Installation Pictures

7.3 Energy Efficient R-32 RAC Experimental Data and Data Analysis

While the efficient RAC systems, Unit #E2-1 and Unit #E2-2, were installed in December 2019 and February 2020, respectively, their operation was interrupted by the civic and business disruption of the COVID pandemic. The pandemic restricted the bank operation so that new RACs were less often operated during the 2020 summer season. Moreover, the bank power was frequently turned off so that communications with instruments were discontinued. Following is a summary based on the test data collected from September 5 to September 25, 2020, for two units in Dar Saada (Unit #E2-1 and Unit #E2-2), and their analysis is provided. For the temperature measurement, indoor temperature and relative humidity, and ODU's inlet and outlet temperatures were measured. For the power consumption, the RAC's total power consumption was measured. Measured data are shown in Figure 30.



(c) Temperature



(d) Power Consumption

Figure 30: Temperature and Power Consumption of Units #E2-1 and E2-2

Highlights of operating characteristics from the measured data are as follows (refer to Figure 5 for 2019 data):

- The temperature variation in 2020 was from 20 to 44°C in 2020, while it was from 15 to 45°C in 2019.
- The room temperature was maintained from 28 to 29°C in 2020 while it was from 24 to 27°C in 2019.
- Two new units were used much less in 2020 than in 2019.

- Unit #E2-2 was used more frequently and thus consumed more power than Unit #E2-1.
- Overall, the power consumption of two new units in 2020 was much less than in 2019.

7.3.1 Daily Average Profile

The daytime ambient temperature, daytime usage ratio, and daytime power consumption during normal working hours (about 8:00 to 18:00) were averaged on a daily basis from September 5 to September 25, 2020, as shown in Figure 31. Moreover, daytime values were averaged for the entire period from September 5 to September 25, 2020, and summarized in Table 11. As can be found from Figure 31 and Table 11, the daytime average ambient temperature in 2020 was 4.7°C higher at 31.4°C than the daytime average ambient temperature at 26.7°C in 2019. This is due to different data collection months: in 2020, data was collected in September but in 2019, it was from mid-September to October. It should be also noted that Unit #E2-1 was rarely used and the RAC working days of Unit #E2-2 were only 21% and 25% of Unit #B2-1 and Unit #B2-2, respectively. Moreover, the daytime average usage ratio in 2020 was 60% to 91% of those in 2019. This reduced operation was associated with the COVID restrictions rather than changes in ambient conditions. The daytime average power of Unit #E2-2 was 17% and 34% of Unit #B2-1 and Unit #B2-2, respectively, and the daily energy consumption of Unit #E2-2 was 20% and 31.5% of Unit #B2-1 and Unit #B2-2, respectively. Due to the reduced operation of Unit #B2-1 and Unit #B2-2, this comparison is not useful.

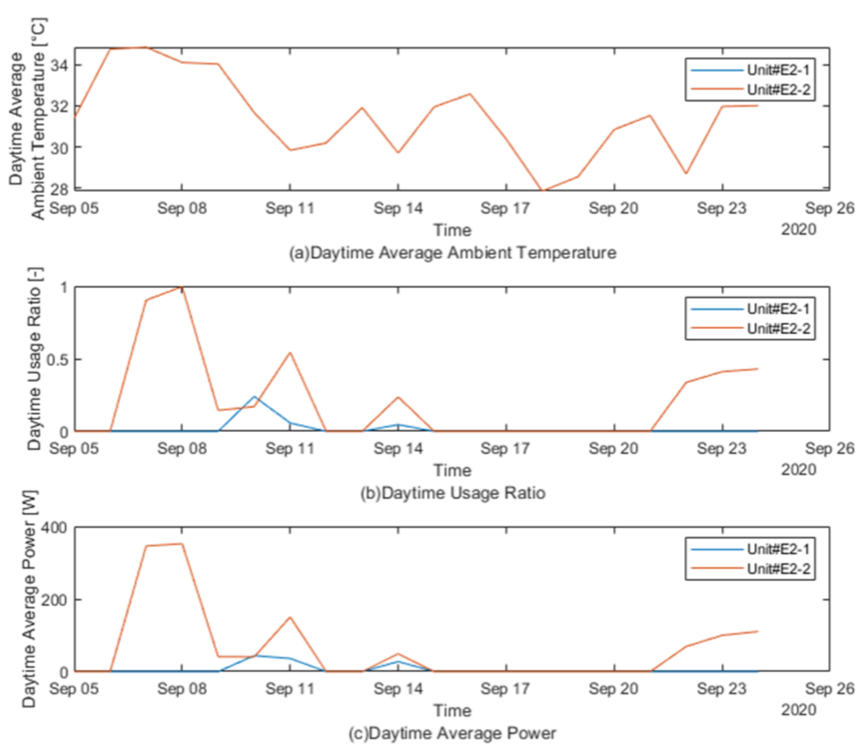


Figure 31: Daytime Average Profiles of Units #E2-1 and #E2-2 in 2020

Table 11: Comparison of 2019 and 2020 Data for Entire Data Collection Period

Unit No.	Daytime Average Ambient Temp. [°C]	Daytime Average Usage Ratio [-]	Daytime Average Power [W]	Total Energy Consumption [Wh]	RAC Working Days/Entire [Day]	Daily Energy Consumption [Wh/Day]
#E2-1	31.4	1.7%	5.4	971.8	3/21	323.9
#E2-2	**31.4**	**20.1%**	**63.0**	**1,133.7**	**9/21**	**1,259.1**
#B2-1	**26.7**	**33.6%**	**369.9**	**168,161.0**	**27/39**	**6,228.2**
#B2-2	26.7	22.0%	183.7	87,889.3	22/39	3,995.0

7.3.2 Data Analysis for A Specific Day

To understand how new RAC units were operated during a typical day in detail, Figures 32 and 33 show temperature and power consumption profiles on September 10, 2020, and September 8, 2020, respectively. September 10, 2020, was selected since both units were operated and September 8, 2020 was selected since the daytime usage ratio reached 1.0. Figures 10 and 11 show the temperature and power consumption profiles from 8 am to 5 pm on October 7, 2019.

Figure 32 shows that Unit #E2-1 and Unit #E2-2 were only operated in the morning from around 8 am till noontime. When the two years' data are compared, we can first find that the room temperature was about 4°C higher in 2020 than in 2019. The power consumption of Unit #E2-2 was only 13.5% of Unit #B2-2 when the ambient was 32°C.

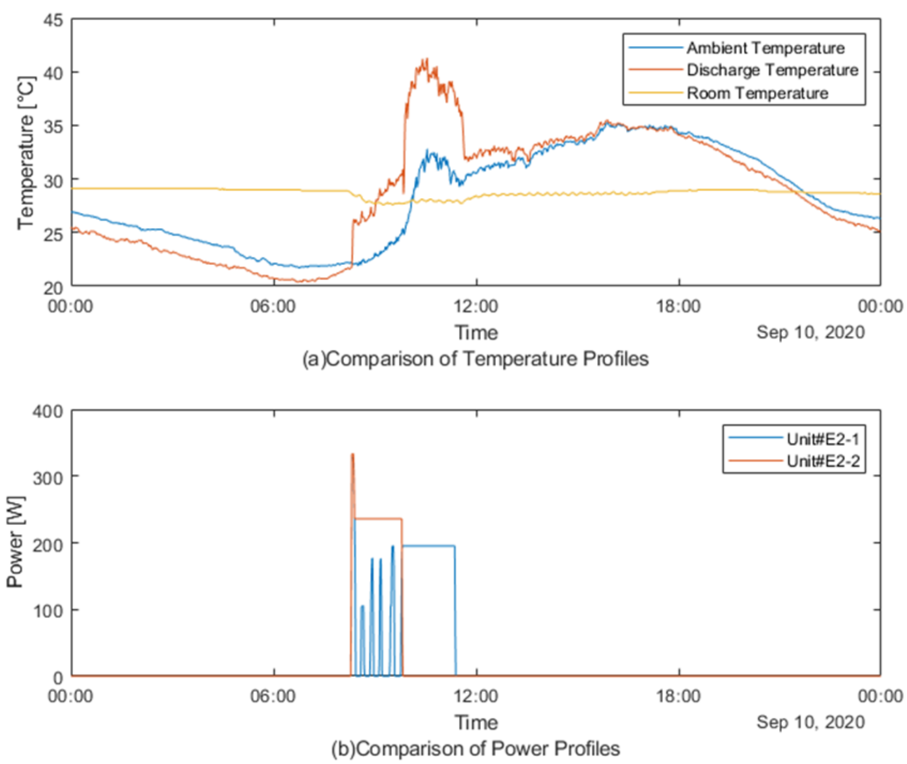


Figure 32: Comparison of Temperature and Power Consumption Profiles on September 10, 2020

Figure 33 shows that on September 8, 2020, only Unit #E2-2 was operated in the morning from around 8 am till 5 pm. Note that the room temperature was about 3.4°C higher in 2020 than in 2019. The power of Unit #E2-2 was only 26.7% of Unit #B2-1 when the ambient was at 35°C.

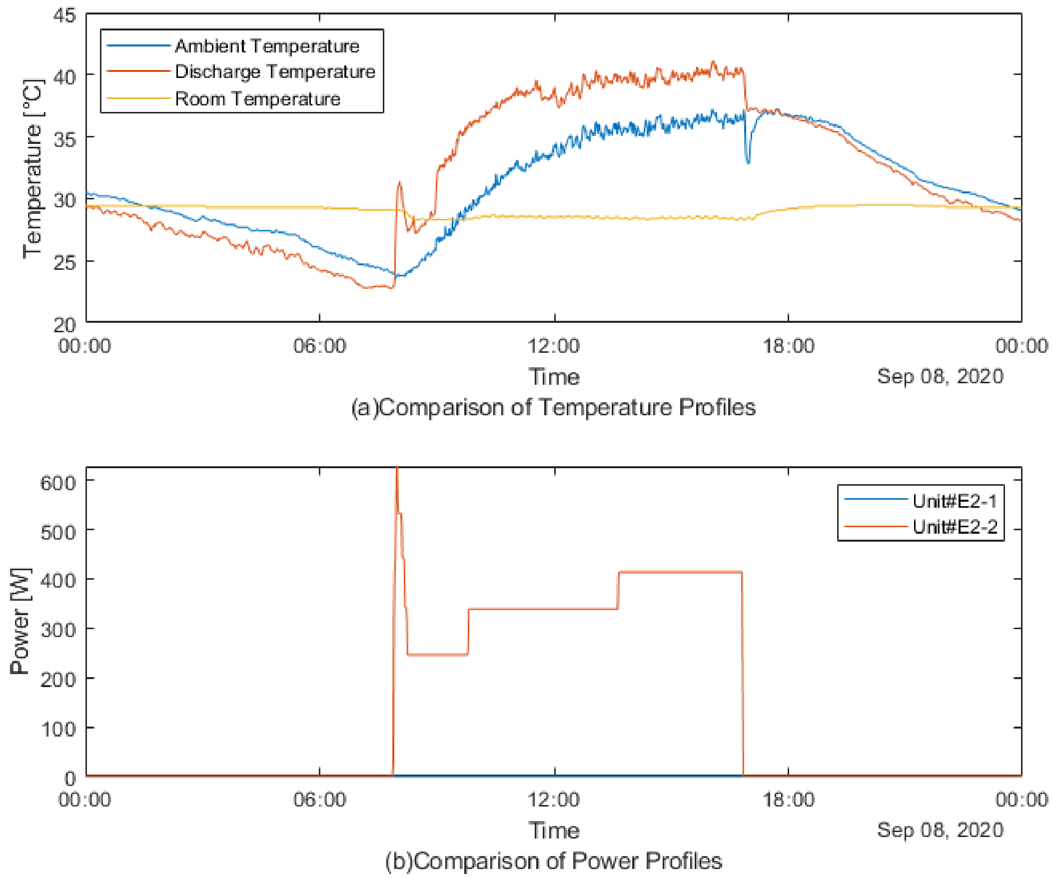


Figure 33: Comparison of Temperature and Power Consumption Profiles on September 8, 2020

7.3.3 Effects of Ambient Temperature on Power Consumption

Figure 34 shows the relationship between power consumption and ambient temperature of Unit #2-1 and Unit #2-2 in 2019 and 2020. The power consumption of Unit #B2-1 and Unit #B2-2 in 2019 was 3.1 to 3.5 times higher than Unit #E2-1 and Unit #E2-2 in 2020, respectively, as explained in the previous section of this report. Besides, the data points were less in 2020 than in 2019 and the most of 2020 power consumption data were concentrated in several levels around 240 W, 340 W, and 440 W. As ambient temperature increases, so does the power consumption. Then the regression analysis was conducted for power consumption. Table 12 summarizes regression results with fitted equations for two enhanced RAC units. Since Units #E2-1 and #E2-2 were operated much less frequently than the baseline units, their regression coefficient of determination

(R2) was poor, especially for Unit #E2-1. This means that these regression equations alone cannot accurately predict the power consumption.

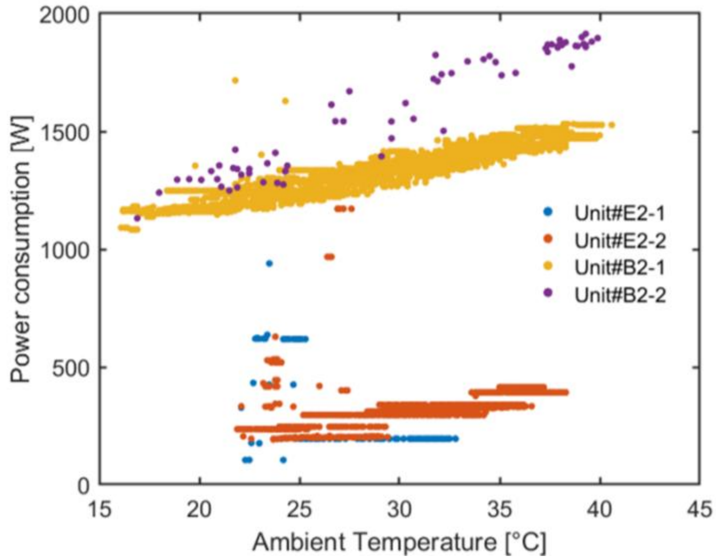


Figure 34: Effects of Ambient Temperature on Power Consumption

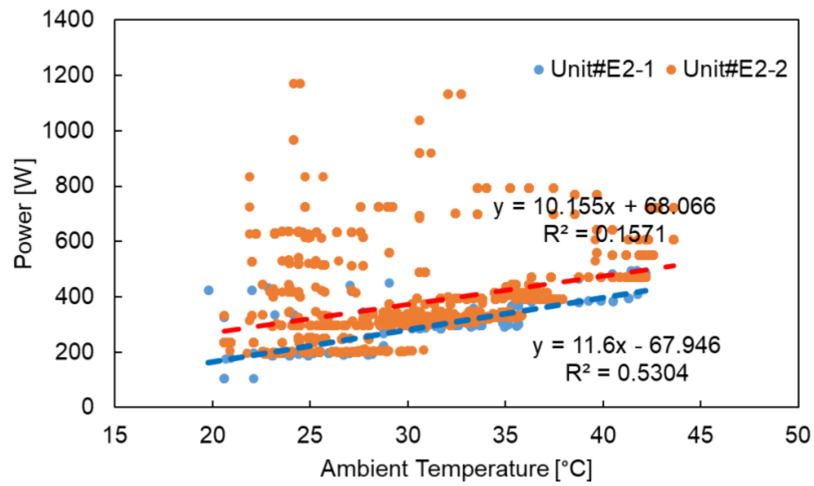


Figure 35: Fitting of 2020 Power Consumption Data

Figure 35 shows the curve fitting of the 2020 power consumption data. Compared with Figure 34, more data in August and October were added. The ambient temperature was predicted by using the Neural Network (NN) method (Hopfield, 1982). The input data was the ambient temperature data from Marrakech airport reported through National Oceanic and Atmospheric Administration's database (NOAA, 2020). The output data was the local ambient temperature from this test site. The data from 2019 was used to build the model and the data from September 2020 was used for testing and validation. Table 12 shows the summary of the two figures. From Table 12, we can find the R^2 of the 2020 data sets is relatively lower than the 2019 data set. The reason is the limited data availability. For the year 2019, we have more than 10,000 data points for each unit. However, for the year

2020, all units were not operated often. For Unit#E2-1, there were only 300 data points available, while for Unit#E2-2, there were 1,000 data points available.

Table 12: Fitted Power Consumption of Test RACs

Unit No.	Fitting equation	The coefficient of determination (R^2)
#B2-1	Power = 866.217 + 16.018 * T_{amb}	0.824
#B2-2	Power = 1050.1 + 19.44 * T_{amb}	0.808
#E2-1	Power = 68.066 + 10.155* T_{amb}	0.157
#E2-2	Power = -67.946 + 11.6 * T_{amb}	0.530

Table 13 shows the comparison of the manufacturer's rated powers and calculated power consumption for three units at 35°C ambient. Unit #E2-2 consumed only 33.8% of the rated power. This is because the unit was operated at a lower frequency due to the higher room temperature set by the user. When considering this unit utilized the variable speed compressor, this unit was operated at near its minimum compressor frequency.

Table 13: Power Consumption of Test RACs

Unit No.	Rated Power [W]	Measured Power @ 35°C [W]	Deviation [%]
#E2-2	1,000 (290 – 1,300)	338.1	-66.2
#B2-1	1,270	1,426.8	12.4
#B2-2	1,270	1,730.5	36.3

Figure 36 shows the predicted power consumption of three units at various ambient temperatures. We can deduce the following observations from this figure:

- Unit #E2-2 power consumption was only 10% to 29% of Unit #B2-1 and 8% to 24% of Unit #B2-2.
- This result comes from the reduced cooling load by setting the thermostat setting to higher room temperature, the operation of the lower compressor frequency, and the higher efficiency of the new unit.

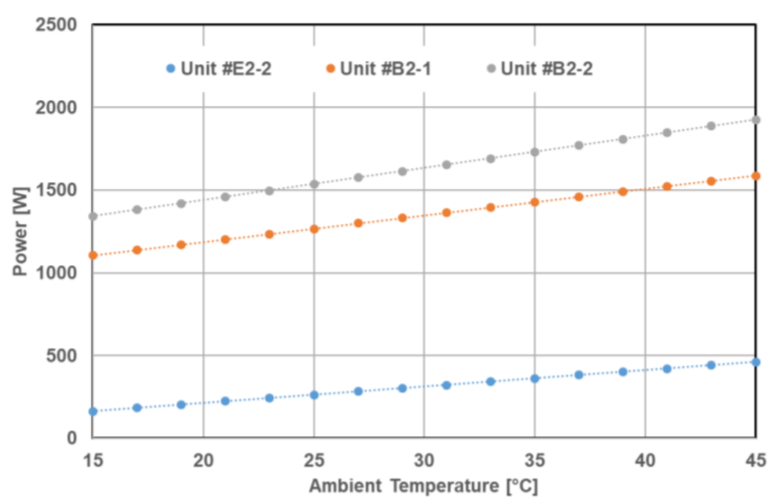


Figure 36: Predicted Power Consumption versus Ambient Temperature

7.4 Energy Efficient RAC Measurement Conclusions

Replacement with properly installed Inverter R-32 high-efficiency RACs was originally expected to reduce energy consumption and carbon footprint by well over 46%. By using the same instruments used in 2019, data were collected for the indoor and outdoor temperatures and power consumption of two new RAC units from September 5 to September 25, 2020, at the Dar Saada branch. Measured data shows the room temperature was about 3.4°C higher in 2020 than in 2019, and the daytime average usage ratio in 2020 was at 60% to 91% of those in 2019. Unit #E2-2 consumed only 10 to 29% of Unit #B2-1 power and 8 to 24% of Unit #B2-2 power. When the daily energy consumption of Unit #E2-2 was compared with Unit #B2-2 as two units had a similar daytime average usage ratio at around 20%, Unit #E2-2 consumed only 31.5% power consumption on a daily basis. However, this finding should be updated based on future measurement when the bank operation becomes normal from the COVID regulations. While the 2020 field measurement was much delayed and hindered by the COVID regulations, this limited finding agrees with the coordinated Brazil Manufacturer's Buyers Club's work in Brazil demonstrated up to 70% saving of new R-32 inverter RACs compared to older RACs with motors operated at single-speed and with improperly installed condensers.

Morocco is active in the global effort to reduce carbon emissions that force climate change. For the building air-conditioning, R-22 has been used but will be phased out soon under the Montreal Protocol due to its harmful effects on the ozone layer and high GWP. Developing countries under the Kigali Amendment to the Montreal Protocol will phase down HFCs by 60% in the next ten years. When considering the expansion of air conditioning demands, early action is needed to leapfrog from the obsolete ozone-depleting and high-GWP refrigerant R-22 to the non-ozone depleting and lower-GWP R-32. It is further recommended to continue monitoring the field performance of the two new efficient R-32 RAC Units for following years to strength these major findings.

Acronyms

AC	Air conditioner or air conditioning
AMEE	L’Agence Marocaine pour l’Efficacité Energétique (Moroccan Agency for Energy Efficiency)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CEEE	Center for Environmental Energy Engineering, University of Maryland
COP	Coefficient of performance
COVID	Corona Virus Disease
GHG	Greenhouse gas
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
IGSD	Institute for Governance & Sustainable Development
ISEER	Indian Seasonal Energy Efficiency Ratio
NN	Neural network
NOAA	National Oceanic and Atmospheric Administration
NGO	Non-governmental organization
NOU	National ozone unit
ODS	Ozone-depleting substance
ODU	Out door unit (inverter, motor, compressor and condenser)
R	Refrigerant (as in R-22, R-32, R-290 and R-410A)
R-22	Hydrochlorofluorocarbon-22 (Chlorodifluoromethane)
R-32	Hydrofluorocarbon-32 (Difluoromethane)
R-125	Hydrofluorocarbon-25 (Pentafluoroethane)
R-290	Hydrocarbon-290 (propane)
R-410A	Hydrofluorocarbon-410A (50% R-32 / 50% R-125)
RAC	Room air conditioner
SEER	Seasonal energy efficiency ratio
SCOP	Seasonal coefficient of performance
UPS	Uninterruptable power supply

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