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DEUTSCHE ZUSAMMENARBEIT

Introducing Eco-Efficient Split Air Conditioners with R-290 in Costa Rica

Implemented by

minae MINISTERIO DE AMBIENTE Y ENERGÍA

DIGECA Dirección de Gestión de Calidad Ambiental

SICA Sistema de la Integración Centroamericana

UNDP Empowered lives. Resilient nations.

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Sustainable and climate-friendly Phase-out of Ozone Depleting Substances (SPODS)

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List of abbreviations

AC	Air Conditioner
BAU	Business-As-Usual (scenario)
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (by their German acronym)
BMZ	German Federal Ministry for Economic Cooperation and Development (by their German acronym)
BTU/h	British thermal unit per hour, used as an alternative to kW (1 kW = 3412.12 BTU/h)
CBD	CEDES Don Bosco
C4	Project 'Cool Contributions fighting Climate Change'
DIGECA	Directorate of Environmental Quality Management
DCC	Directorate of Climate Change
EE	Energy Efficiency
FS	Samuel Foundation
GCF	Green Climate Fund
GHG	Greenhouse Gases
GIZ	Deutsche Gesellschaft für internationale Zusammenarbeit GmbH
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HEAT	HEAT GmbH (Habitat, Application and Technology)
HPMP	HCFC Phase-out Management Plan
ICE	Costa Rican Institute of Electricity
IKI	International Climate Initiative (of BMU)
INA	National Learning Institute of Costa Rica
MEP	Ministry of Public Education of Costa Rica
MINAE	Ministry of Environment and Energy of Costa Rica
MLF	Multilateral Fund of the Montreal Protocol
MOPT	Ministry of Public Works and Transportation of Costa Rica
NDC	National Determined Contributions
SDG	Sustainable Development Goals
UNIDO	United Nations Industrial Development Organization
GWP	Global Warming Potential
UNDP	United Nations Development Program
RAC	Refrigeration and Air Conditioning
EER	Energy Efficiency Radius
SEER	Seasonal Energy Efficiency Ratio
SAE	Society of American Engineers
ODS	Ozone Depleting Substance
SEPSE	Secretariat of Planning of the Energy Sub-sector
SICA	Central American Integration System
SPODS	Project "Sustainable and climate-friendly Phase-out of Ozone-Depleting Substances"
IRR	Financial internal rate of return
ToT	Training of Trainers
ECU	Energy Coordination Unit (SICA)
4E	Program for the Promotion of Renewable Energies and Energy Efficiency in Central America

PROJECT BACKGROUND

The introduction of eco-efficient air-conditioning units, which operate with the natural refrigerant R-290, has been driven by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and by the Directorate of Environmental Quality Management (DIGECA), of the Ministry of Environment and Energy (MINAE) of the Government of Costa Rica, in collaboration with the Central American Integration System (SICA). This initiative would not have been possible without the support of different international projects and programs.

The Cool Contributions fighting Climate Change (C4) project, which is implemented by GIZ, has the objective of supporting the Government of Costa Rica in reducing the emission of Greenhouse Gases (GHG) from the refrigeration, air conditioning and foam sector in order to comply with the Nationally Determined Contributions (NDC).[1] The project is implemented by DIGECA's National Ozone Unit and GIZ. C4 is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under its International Climate Initiative (IKI). This project contributed with the donation of 50 eco-efficient air conditioning units (R-290), tools for three training centers, consumables and facilitation of the trainings, that involved the participation of international instructors.

The program "Promotion of Renewable Energies and Energy Efficiency in Central America (4E)" was commissioned to GIZ by the German Federal Ministry for Economic Cooperation and Development (BMZ) and has been implemented in the region since 2012. In its third phase (2019) the 4E program aims to reduce energy consumption in Central America, working with representatives from all countries in the area (Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama) to promote energy efficiency measures. The program also supports regional information exchanges and collaboration with the private sector to successfully incorporate renewable energy generation into the regional electricity system. The 4E program provided the donation of 50 additional eco-efficient air conditioning units (R-290), installation of a smart energy efficiency monitoring systems and the facilitation of trainings.

The project "Sustainable and climate-friendly Phase-out of Ozone Depleting Substances (SPODS)" supports selected countries in Latin America and the Caribbean in their transformation processes in fulfilling their obligations under the Montreal Protocol related to the phase-out of Ozone Depleting Substances (ODS) and current HFC mitigation. SPODS is funded by the European Union and BMZ and is jointly executed by GIZ and UNDP in Costa Rica. GIZ's SPODS project collaborated with the realization of the previously mentioned trainings that involved the participation of international instructors, materials for the training of participants as well as the monitoring of the energy efficiency of the donated units.

1 Other partner countries of the C4 project include Grenada, Iran, Philippines and Vietnam.

Finally, in the case of Costa Rica, the United Nations Development Programme (UNDP) is implementing the following projects: "HCFC Phase-out Management Plan" (HPMP), enabling activities for "HFC phase-down (Kigali Amendment)" and "Institutional Strengthening of the Ozone Technical Office" in cooperation with DIGECA. The UNDP contributed with the facilitation and access to tools for the realization of the trainings at CEDES Don Bosco (CDB), refrigerators with R-600a, consumables and materials for trainings to INA, MEP, Samuel Foundation (FS) and also CDB, as well as with the financing of the installation of some of the units.

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We thank the Directorate of Environmental Quality Management (DIGECA) of the Ministry of Environment and Energy (MINAE) of the Government of Costa Rica for their cooperation in this project in general. In addition, we thank INA, FS, MEP, CDB, MOPT, ICE and Hotel Ambassador for their cooperation in this project. We are grateful for the collaboration and support of all the people, institutions and companies that assisted in the data collection and advice for this study.

SUMMARY

GIZ and the Ministry of Environment and Energy (MINAE), in collaboration with the Central American Integration System (SICA), developed a demonstration project to introduce eco-efficient air conditioning (AC) equipment that operates with ultra-low global warming potential (GWP) refrigerants, such as R-290, and with high energy efficiency. In this regard, two strategies were implemented to facilitate the expansion of the market for split type AC equipment operating with R-290 refrigerants in Costa Rica. These are based on the donation of 100 split type AC units with R-290, imported from the manufacturer Godrej, in India.

At first, a training program was developed so that national and international technicians from different institutions could develop skills in the handling of equipment with hydrocarbons-based refrigerants, in this case R-290 and R-600a. In December 2018, the first training was conducted by an instructor from India, from the manufacturing company Godrej. International instructors from Spain and Colombia also supported the second and third trainings, where several national and international instructors participated. Local instructors, that participated in at least two of the previous trainings, of INA and the Samuel Foundation conducted the following trainings. The objective of these trainings was to train other instructors and technicians, with the idea of incorporating split AC with R-290 into the curriculum of their training institutes. AC units, equipment and tools were donated to four national training institutes.

The second activity of the project was the execution of demonstration projects with ACs using R-290. Based on a national contest, three main institutions received 20 units of AC with R-290. The strategy of the demonstration project was to show the advantages of eco-efficient AC equipment with R-290 compared to conventional AC equipment. Some of the imported equipment was donated to actors interested in being part of the project. Through an energy monitoring program, two intensive studies of more than 24 hours were carried out, comparing Godrej units against conventional ones. The studies were conducted at the Ambassador Hotel and MOPT's central offices, both located in San José. Many energy monitors were also installed at these locations. By analysing the historical data and contrasting it with the data of the intensive tests, it was determined that the eco-efficient units with R-290 consume at least 40% less electrical energy compared to conventional reference units installed in buildings of the participating institutions. Historical energy monitoring data of the different units installed in other buildings was also analysed.

Based on the results of the intensive studies and the analysis of long-term energy monitoring, savings in operating costs were estimated for the eco-efficient equipment, compared to conventional equipment with the same or similar thermal capacity (BTU). After ten years, the investment of an eco-efficient unit can be potentially recovered. In addition, by theoretically evaluating the maintenance and installation costs, it was concluded that there is an internal rate of return (IRR) of 38.19% for 12,000 BTU/h units and 44.61% for 18,000 BTU/h units, when compared to the bestselling Inverter technology units in 2019.

Furthermore, a mitigation potential of 2.2 tons of CO_2eq was estimated when comparing new technology with conventional equipment. It should be noted that, due to the high contribution of renewable energy sources in Costa Rica, indirect emissions mitigation actions in the RAC sector have a low impact. The greatest potential for mitigation lies in the reduction of emissions from refrigerants. Refrigerant R-290 has an ultra-low GWP compared to conventional refrigerants.

Educational materials have been prepared and there are currently standards in place to support the implementation of this type of technology. In addition, safety standards for Costa Rica have been developed and introduced. Moreover, national and international/regional events have been held to inform and educate policy decision makers and some private sector representatives on the subject. Consequently, there is a great upscaling potential in multiplying the knowledge and these technologies.


ComfortStar

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INTRODUCTION

GIZ and the Ministry of Environment and Energy (MINAE) jointly promote the installation and use of eco-efficient, non-ozone depleting air conditioners with a minimal global warming potential (GWP). To achieve this goal, a project was proposed in collaboration with the Central American Integration System (SICA), seeking to promote the use of split type air conditioning (AC) equipment that has high energy efficiency and uses refrigerants with a low carbon footprint. In order to promote the introduction of this type of equipment, GIZ, in cooperation with DIGECA/MINAE, imported 100 AC split type units with the ultra-low GWP refrigerant R-290 (GWP 3)[2]. These units also use compressors with *Inverter*[3] technology, which is more efficient than conventional compressors. Appliances with these two technologies will be referred to as eco-efficient units throughout this publication. The R-290 refrigerant is more efficient than conventional refrigerants due to its thermodynamic properties.[4] In these units, both factors contribute to attaining a SEER[5] efficiency rating of 20.68 BTU/Wh., which is higher than average units sold in Costa Rica (SEER rating of 19 BTU/Wh., in 2019).

Refrigerants play a major role in contributing to global warming in the refrigeration and air conditioning (RAC) sector, as they are responsible for direct emissions. Direct emissions occur when the refrigerant leaks or is fully released during operation or during equipment disposal or replacement. To characterize the impact, each substance has an associated Global Warming Potential (GWP), which is basically a way to estimate the kilograms of refrigerant into kilograms of CO_2 equivalent. Conventional AC refrigerants have GWPs between 1760 kg CO_2eq./kg and 1923 kg CO_2eq./kg, while the natural refrigerant alternative has ultra-low GWP values such as R-290 with a GWP of only 3 kg CO_2eq./kg.

Due to the high contribution of renewable energy sources to electricity generation in Costa Rica,[6] mitigation actions in the RAC sector will have a lower impact on indirect emissions. The greatest potential for mitigation lies in the reduction of direct emissions.[7]

The pilot project to be described is unique in the Latin American region. Never before have AC units with R-290 been introduced with this depth and scope. On another occasion, GIZ Proklima conducted a series of AC equipment trainings with natural refrigerants, in this case R-290, in Colombia. However, these trainings cannot be compared to the present project. The aim is to lay the foundations for the use of this type of technology in different sectors of the country and to be an example to follow in terms of energy efficiency and low environmental impact in the RAC sector for other countries in the region.


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Photo 1. Required tools for the installation of AC equipment with R-290.

2 IPCC, 2005: Special Report on Safeguarding the Ozone and the Global Climate System.
3 Frequency variation technology that controls the speed of the compressor, resulting in a much more efficient operation.
4 GIZ, 2019: R-290 Split Air Conditioners Guide.
5 In English as: Seasonal Energy Efficiency Ratio (SEER).
6 Presidential House, 2019: For the fifth consecutive year, Costa Rica will exceed 98% of renewable electricity generation.
7 Direct emissions are those emitted by the refrigerant of the RAC sector equipment. Indirect emissions represent the environmental impact of electricity production for the operation of equipment in the RAC sector.

Prior to the development of the project, steps and processes were carried out to dimension the scope and objectives of the project. For example, a Tier 2 GHG emissions inventory was conducted for the RAC[8] sector. First, the current situation in the country was evaluated with respect to these issues. The presence of AC units and the knowledge of the technical sector in this area were investigated. Next, the purchase and donation of 100 eco-efficient units to various public institutions, the interested private sector and training institutes was planned.
The split AC units were procured through two projects implemented by GIZ Proklima: *Cool Contributions to fighting Climate Change* (C4) and *Promotion of Renewable Energies and Energy Efficiency in Central America* (4E). Projects supported the purchase of 50 units each (18 units of 12000 BTU/h and 32 units of 18000 BTU/h each project), for 100 units in total, with a total investment of around $50,000. Additionally, the C4 project invested around $50,000 in tools and training consumables.

A third project, *A Sustainable and Climate-Friendly Phase-out of Ozone Depleting Substances* (SPODS), covered additional costs, including international instructors. The United Nations Development Program (UNDP) collaborated with the purchase of tools to CEDES Don Bosco (CDB), as well as materials and consumables for INA and Samuel Foundation. The imported AC Godrej's[9] models have been examined by an external laboratory in India, which attested to the quality of the equipment and its energy efficiency.[10]

The project consists of two strategies: 1) training and 2) a demonstration project with R-290 ACs. Of the imported 100 AC units with R-290, 67 were used in the demonstration project. They were installed in buildings of different companies and institutions. Each equipment was installed with a device that monitors energy use and other variables of interest, such as temperature and humidity. These devices were also installed on old AC equipment that were already installed in the different buildings, to monitor and compare the energy use of both types of ACs. The energy monitoring was realized by the projects, 4E, SPODS and C4, which also supported the present study.

Photo 2. Installation of AC units with R-290 refrigerant as part of a training at the GIZ office, Pavas.

Most of the remaining imported units were delivered to four training institutes to be used as learning tools, and the few rest were put aside as spare parts. Tools and consumables were also donated to the training institutes for training and education with R-290 and R-600a. The trainings included handling of equipment with R-600a, another natural refrigerant used for domestic refrigeration.

The refrigerant gas R-290 is flammable under certain conditions, so technical personnel must be instructed in procedures to avoid flammable atmospheres, eliminate sources of ignition, and reduce the consequences of combustion. It should be noted that R-290 has the best thermodynamic properties possible when compared to other AC split type refrigerants such as R-22, R-407C and R-410A.[11] These properties and other characteristics make R-290 more efficient than other refrigerants. ACs with this refrigerant usually require less refrigerant charge.

8 MINAE, 2019: Refrigeration and Air Conditioning. Greenhouse Gas Inventory for Costa Rica (2012-2016).
9 Manufacturer of this type of A/C units with natural refrigerant.
10 Sierra Aircon Pvt. Ltd., 2017: Test Report, Cooling Capacity Test for Split Type (Inverter) Air Conditioners.
11 GIZ, 2019: R-290 Split Air Conditioners Guide.

Photo 3. Installation of eco-efficient unit at DCC, during the R-290 training.

The objective of the installation of these units, within the demonstration project, was to monitor energy consumption and to compare the energy efficiency of new and existing units. In addition to the long-term monitoring, carried over more than a year, two intensive tests were carried out for more than 24 hours to compare in greater detail the operation of eco-efficient units and conventional units in greater detail.

Based on the intensive and long-term energy monitoring results, different approximate values of monetary savings were obtained when preferring an eco-efficient equipment compared to a conventional AC unit with HFCs (average installed and average sales in Costa Rica) in different sectors, such as residential, commercial, and public. By the year 2019, when the eco-efficient units were imported, the most sold conventional AC units with Inverter technology with R-410A refrigerant in the market had an average SEER of 19 BTU/Wh rating, so they were less efficient than the eco-efficient units introduced by this project.[12] The average AC equipment installed in Costa Rica had an EER of 3.2 Wt/We in 2016.[13]

In addition, the new R-290 units do not require recharges since they have more rigorous warning and leak prevention systems than units with conventional refrigerants. These units, in addition to the failure systems that immediately shuts down the equipment, are installed with mitigation measures that greatly reduce the risk of flammability, such as location within the room and refrigerant charge (which is usually less than that of a conventional refrigerant).[14] Furthermore, about 70% of the refrigerant in the condensing unit in any given moment, which is placed outside the room, minimising the risk of explosion.

The use of eco-efficient units therefore has a great potential for mitigation, both economically and environmentally. A conventional AC unit emits 3.7 tons of CO_2eq over 10 years, while an eco-efficient unit emits 2.2 tons less CO_2eq over 10 years.[15] Therefore, by 2050, potential savings of 300,000 tons of CO_2eq per year in unitary AC equipment can be attained, according to the mitigation and energy efficiency scenario.[16]

As the first project of this magnitude in the region, the aim is to scale up the strategies implemented, to train more instructors and technicians, to obtain more evidence through energy monitoring, and thus lead the definitive implementation of eco-efficient AC teams in the country and the Latin American region.

12 GIZ, 2020: Market study on energy efficiency of AC split type in Costa Rica.
13 MINAE (2019) Greenhouse Gas Inventory for Refrigeration and Air Conditioning for Costa Rica (2012-2016).
14 See Annex 21 and 22.
15 According to 13% average refrigerant leakage rate per year in Costa Rica in AC split type equipment based on, GIZ, 2020a: Leakage study in split type air conditioning equipment in Costa Rica.
16 MINAE (2019) Greenhouse Gas Inventory for Refrigeration and Air Conditioning for Costa Rica (2012-2016).

Photo 4. Participant of the first training held at the National Learning Institute of Costa Rica (INA).


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TRAININGS ON R-290 SPLIT ACS

The effective insertion and integration of AC equipment with R-290 refrigerant is a process that requires to be accompanied by a parallel strategy of education and training. R-290 refrigerant is a hydrocarbon, which is flammable in certain conditions. Therefore the units require additional safety equipment and a different handling of the gas is necessary. Part of the GIZ demonstration project in cooperation with DIGECA, was to carry out a series of Trainings of Trainers (ToTs), from different national and international training institutes.

Previous efforts have been undertaken by GIZ Proklima to train members of the RAC sector in natural refrigerants. Technicians, trainers, instructors, policy decision makers from INA, MEP, DIGECA, and other private sector companies participate in different versions of the "Cool Training" activity in Germany. The Cool Training is a series of international trainings in the safe use of natural refrigerants in the RAC sector. These trainings promote globally sustainable air conditioning technologies and focus on training personnel from developing countries.[17]

The training strategy developed is unprecedented within the RAC sector in Latin America. Previously, GIZ Proklima had conducted a series of trainings for ACs with R-290 in Colombia, but not like the framework of this project. Six trainings were held in Costa Rica, with support from foreign instructors from India, Spain, and Colombia. A total of 98 national and foreign instructors and technicians were trained.

To participate in the training, it was necessary to have the certification of good practices in the handling of refrigerants, granted by DIGECA.[18] The training was composed of theoretical and practical modules, which included evaluation activities. The complete curriculum of the modules can be seen in Annex 20. The modules included the following topics:

- Training in welding.
- Handling of natural refrigerants and their cylinders.
- Safety and risk precautions in the handling of natural refrigerants.
- Design of a sealing system.
- Installation, commissioning, and maintenance of an equipment with R-290.
- Regulations, safety standards and guidelines.
- Procedures, tools, and equipment for the use of flammable refrigerants.
- Refrigerant recovery.
- Repair of domestic refrigerators with R-600a.

Each training day ended with an evaluation.

17 Green Cooling Initiative: https://www.green-cooling-initiative.org/cool-training/
18 DIGECA (2019): Requirements for applying for the "Good Refrigeration and Refrigerant Handling Practices" card.

Table 1. List of trainings realized.

Date and place	Topic	Participating institutions	Participating countries
3 to 6 of December 2018 INA, DCC, MyTransport GIZ, Hotel Ambassador	ToT with manufacturing house (India) AC R-290 Coach: Godrej	**Total: 18** INA, MEP, Samuel Foundation, CDB and importers (Leaho, Omega and Beirute)	Costa Rica
27 to 31 of May 2019 INA	ToT AC R-290 and R600a domestic refrigeration Coach: HEAT (Spain) and independent (Colombia)	**Total: 16** SSSIR S.A. de C.V. Instituto Tecnológico de León, Samuel Foundation, CEDES Don Bosco, INA, IPN	Costa Rica Mexico
3 to 7 of June 2019 INA	ToT AC R-290 and R600a domestic refrigeration Coach: HEAT (Spain) INA	**Total: 16** INA, INADEH, Ozanam Professional Association, CEV, JTCB INSAFOR, Universidad Galileo, Instituto Técnico Vocacional Dr. Imrich Fischmann, Cuba Energy, Salesianito MADES, Samuel Foundation	Panama Honduras El Salvador Guatemala Cuba Paraguay Costa Rica
10 to 14 of June 2019 INA	ToT AC R-290 and R600a domestic refrigeration Trainer: INA	**Total: 16** INA, UNDP, ICE, Beirute, IN Fund, GTOZ, Omega, Samuel Foundation	Venezuela Nicaragua Panama Cuba Costa Rica
9 to 13 of December 2019 Samuel Foundation	ToT AC R-290 and R600a domestic refrigeration Trainer: Samuel Foundation	**Total: 16** MEP, ICE, Refrimundo, CEDES Don Bosco, INA, Beirute, Omega	Costa Rica
16 to 20 of December 2019 Samuel Foundation	ToT AC R-290 Coach: Samuel Foundation	**Total: 16** Samuel Foundation, Tecniservcios H 2000, Seytel S. A. de C.V. S y M Ingeniero S.A. de C.V. HIMO, Tundra, CCSS, ICE, INA, MOPT, Refrimundo	El Salvador Costa Rica
Total	**6 ToTs**	**98 participants**	**11 countries**

Photo 5. Installation of R-290 unit at the Hotel Ambassador during the training. The tecnician is accompanied by Godrej's instructor, Shneekant Jamble.

A series of contests were held to select the beneficiaries and participants of the trainings. Selected companies and institutions benefited from the 67 Godrej units for the demonstration strategy. These companies and institutions accepted the AC units through an agreement with DIGECA and GIZ, in which they consented to take responsibility for the installation and maintenance of the equipment, and monitoring of energy consumption. A second contest selected three companies from the RAC sector, which would receive training in the installation of eco-efficient units. Additionally, technicians from INA, MEP, FS and CDB participated in the training. Finally, another contest was held for different companies/technicians to apply for a place to participate in the training sessions.

The implemented trainings are called ToT (Training of Trainers). A total of six ToT were held between December 2018 and December 2019, 98 trainers and technicians from 11 countries attended. In December 2018, the first ToT was conducted, with the participation of a trainer from India, specifically from the manufacturer Godrej. The following training was conducted by a Spanish trainer, representing HEAT GmbH, together with an independent trainer from Colombia. The trainer from Spain accompanied the process in an additional training with a qualified trainer from INA. The following sessions were conducted by INA or Samuel Foundation trainers, who had participated in at least two of the previous trainings.

The GIZ approach to working in this area at a global level consists of three phases: capacity building (training), certification and registration. Training of specialized technicians, both theoretical and practical, linked to the national technician certification program, is the best way to establish and verify the competence of the personnel handling refrigerants, performing installations, and carrying out maintenance. All capacity building activities, as well as support to training centers, have been carried out in accordance with international best practices. The trainings can be completed in only one week.

Photo 6. Installation training of AA equipment split type with R-290, GIZ, Pavas.

The material prepared for these trainings was the product of GIZ Proklima's experience of more than 20 years in the field, where they have developed training strategies in sustainable technologies such as these trainings and the Cool Training.[19] The modules were prepared according to different international safety standards and procedures.

There are many different standards for various RAC applications using natural hydrocarbon-based refrigerants such as R-290 and R-600a. Among the international standards and regulations, the European standard EN 378 is particularly prominent[20] and was used to design the training modules. Table 2 lists the relevant standards in force in Costa Rica.

Table 2. Safety standards implemented in Costa Rica.

National Technical Standard
INTE / ISO 817:2019: Refrigerants – Designation and safety classification.
INTE / ISO 5149-1: 2020 (MOD) Cooling systems and heat pumps. Safety and environmental requirements. Part 1: definitions, classification, and selection criteria.
INTE / ISO 5149-2: 2020 (MOD) Cooling systems and heat pumps. Safety and environmental requirements. Part 2: design, construction, testing, marking and documentation.
INTE / ISO 5149-3: 2020 (MOD) Cooling systems and heat pumps. Safety and environmental requirements. Part 3: installation site.
INTE / ISO 5149-4: 2020 (MOD) Cooling systems and heat pumps. Safety and environmental requirements. Part 4: operation, maintenance, repair, and recovery.
INTE W94: 2020: Cooling systems and heat pumps. Staff competence.

19 Green Cooling Initiative: Cool Training.
20 UNE, Spanish Standardization (2017): UNE-EN 378-4:2017.

Currently, GIZ collaborates with INTECO to generate standards for the different applications of the RAC sector that use natural refrigerants and to adapt international standards to local context.[21] A list of safety standards currently under development in the country is presented in Annex 4.

Of great interest is INTECO's standard, INTE E14 – 1: 2019[22], which provides guidelines on energy efficiency in air conditioning equipment up to thermal capacities of 65,000 BTU/h (Table 3 and 4).

Table 3. Minimum Seasonal Energy Efficiency Ratio (SEER) level for air conditioners with variable refrigerant flow, Inverter technology.[23]

Classification of the equipment	BTU/h	SEER Wt/We (BTU/hW)
Roof Top type	Up to 19,050 (65,000)	4.39 (15)
Split type, central with ducts		
Split type, direct discharge, no ductwork	Up to 10,600 (36,168)	4.68 (16)
	Greater than 10,600 (36,168) until 19,050 (65,000)	4.39 (15)

Table 4. Minimum Energy Efficiency Ratio (EER) level for air conditioners, "on/off" technology.[27]

Classification of the equipment	BTU/h[24]	EER[25] Wt/We (BTU/hW)[26]
Window type	Up to 5859 (24,000)	3.22 (11)
Roof Top type	Up to 19,050 (65,000)	3.22 (11)
Split type, central with ducts		
Split type, direct discharge without ducts		

With ToT, the reach of the R-290 and R-600a refrigerant training creates a multiplier effect, as each person attending this training is a multiplier who can train other technicians. In addition, the training institutes can offer courses on this subject using the donated AC equipment with R-290 and tools. During the trainings, the participants were also instructed on how to monitor energy efficiency. In the near future, the handling of equipment with natural refrigerants will be included in the curriculum for the training of air conditioning and refrigeration technicians.

21 More information on RAC industry standards and natural refrigerants can be found at GIZ Proklima (2018): International Safety Standards in Air Conditioning Refrigeration and Heat Pump UNEP (2017): Application of Safety Standards to RACHP.
22 INTECO (2019): INTE E14-1:2019.
23 Ibid.
24 Nominal values of BTU/h.
25 In English language as: Energy Efficiency Ratio (EER).
26 The EER value is determined on the condenser and evaporator assembly.
27 Ibid.

In the area of technical service of AC equipment, there is a great gender disparity among technical personnel. It is therefore not surprising that women make up less than 1% of AC service technicians. Evidence of this is that there was only one female instructor among the participating instructors. However, of the 98 participants, four were women, which is more than usual.

Within the strategy and action plan of GIZ in collaboration with DIGECA, it is proposed to establish a modular training system. For Costa Rica to be ready and equipped to adopt the new efficient climate and AC technology, it needs informed and well-trained technical service personnel, as well as training centres equipped with the latest environmentally friendly technology. Within this strategy, it is aimed to develop several training centres to train more technicians. With the training program carried out in this project, a first data base containing technicians and trainers trained in the handling of refrigerants R-290 and R-600a was generated.


Godrej
POWER
SAVING
GREEN
INVERTER AC
5.20 ISEER

DEMONSTRATION PROJECT

The implementation of energy monitoring of eco-efficient and previously installed AC split type units in each building generates a large amount of data that allows to observe the behaviour of each unit, no matter what type, in reality.

It is possible to know a lot in advance about the performance of AC equipment with its specifications. However, it is not possible to offer the best possible forecast regarding its energy consumption and the possible savings in the use of eco-efficient equipment, such as the units imported in this project. The performance will vary according to latitude, orientation of the sun, volume and occupation of the room and the nature of use, i.e. it is exceedingly difficult for two units to be used in the same way. For these reasons, it is challenging to forecast energy consumption and other associated factors without field quality data. Energy monitoring offers the opportunity to examine data over long periods of time, thus minimising the effects on differences in use.

In addition to long-term energy monitoring, two intensive tests were conducted in the demonstration project, one at the MOPT headquarters and the other at the Ambassador Hotel. In these tests, eco-efficient units were used, as well as conventional units that were already installed. The tests were carried out for more than 24 hours, at the same time and under remarkably similar conditions. In this way, it was possible to observe the differences in operation in terms of electricity consumption and efficiency of conventional AC equipment compared to eco-efficient equipment.

Methodology

The project contemplates implementing an energy monitoring, which will offer quality data for its respective analysis. Using and obtaining quality data is necessary for correct feedback and progress towards the proposed objectives, not only for this project, but at the country level for the reduction of the carbon footprint and the environmental impact in terms of indirect emissions. Energy monitoring also seeks to improve energy efficiency in the use of AC equipment.

Photo 7. R-290 AC unit installed in a room at the Hotel Ambassador, San José.

An AC unit impacts the environment in two ways: direct emissions and indirect emissions. Direct emissions refer to the impact of refrigerants, while indirect emissions account for the impact of the power grid and electricity consumption. Indirect emissions consider how energy is obtained from the grid and how sustainable and environmentally friendly the energy sources are. In the case of Costa Rica, where electricity comes almost entirely from environmentally friendly sources[28], the electricity grid contributes little to these emissions. This means the largest share of emissions in the country is due to direct emissions. It is particularly essential in the case of Costa Rica to have efficient equipment and ultra-low GWP refrigerants since this is where the greatest mitigation potential lies.

As mentioned above, imported AC split type units work with R-290 refrigerant. In addition, they have *Inverter* technology and a rather high SEER rating of 20.68 BTU/Wh. It is of interest to monitor these units operating regularly and in office spaces to be able to quantify the savings in electrical expenditure. With available field data, these technologies can be promoted and lead to greater environmental and economic sustainability in the AC sector.

The energy monitoring system used consists of two fundamental parts:

· SonOff POW1/2 power consumption and flow sensors, with a modified open-source operating system ("firmware") adapted to the project.

· A centralized "cloud" system for receiving, collecting, maintaining, and evaluating data.

The monitoring devices are electrically connected in series to the AC equipment and constantly measure parameters such as voltage, current, active/reactive components and the accumulated energy consumed, and transmit the values to the central server using the standardized MQTT protocol (ISO/IEC 20922).

The monitoring devices optionally also have sensors for different environmental parameters such as temperature and/or relative humidity.

The monitoring system was developed and implemented as a prototype for a broader collection and evaluation platform for a low-cost "internet of things" node energy monitoring sensor network based on open and free code communication protocols.

Several sensors also have a "QR code" that allows an end user to access an information portal of the GIZ energy efficiency project on a web page and view the energy consumption history of the scanned sensor.

The data collected may also be shared anonymously with interested individuals and institutions, under the "Open Data" philosophy, if requested.

Photo 8. Example of the energy monitoring devices.

28 Presidential House, 2019: For the fifth consecutive year, Costa Rica will exceed 98% of renewable electricity generation.

The monitoring system faced several unforeseeable challenges in its implementation. Among these are non-permissive IT policies of some locations, extremely variable AC usage patterns and challenges in the electrical installations. In some locations users seem to have used AC particularly sparingly to save energy, resulting in less statistically interesting data. To address these challenges, intensive scheduled tests were conducted at two locations, and filters were applied to the historical data obtained. These filters aimed at selecting the days of ordinary use of the equipment, i.e. when it was fully used and not switched on accidentally or for less than 30 minutes. This allowed observing data of higher quality and relevance, and in a way equalizing the conditions to compare the performance of different equipment.

Ministry of Transport Costa Rica (MOPT)

Twenty units were assigned to MOPT's central offices in San José. They were used as a replacement for conventional and inefficient AC units. One energy monitoring device was installed on each unit. In addition to the long-term energy monitoring, the intensive study was carried out over three days for a total of 63 hours.

Two reference AC units and two eco-efficient units recently installed by the GIZ in offices of comparable size were selected.

Table 5. Main characteristics of the AC equipment under study.

Unit	BTU/h	Refrige-rante	Tecno-logía	Eficien-cia (REEE)
GIZ 1 Godrej[29]	12,000	R-290	*Inverter*	20.86
REF 1 Samsung[30]	12,000	R-22	Conven-tional	3,6 Wt/We (EER) 12.28[31]
GIZ 2 Godrej	18,000	R-290	*Inverter*	20.86
REF 1 Innovair[32]	24,000[33]	R-22	*Inverter*	14.44

The test was held from 3:00 p.m. on Friday, 2 August 2019 and 5 August 2019. All the units were programmed to maintain a temperature of 20°C during the day and thus lower than the ambient temperature outside the building.

29 General specifications of the Godrej units in Annex 2.
30 Conventional split type unit that is regularly used during office hours.
31 Estimated data. It should be mentioned that calculating the SEER value for a conventional unit (fixed speed), is very difficult. This value is only an approximation.
32 Split type Inverter unit that is regularly used during office hours, between five or six hours.
33 Data is taken from this unit and a factor of 0.75 is applied, to have approximate data from a unit of 18 000 BTU/h.

Photo 9. R-290 GIZ Eco-efficient AC unit 1.

Photo 10. Reference AC equipment.

Photo 11. R-290 GIZ 2 eco-efficient AC units.

Photo 12. Reference AC equipment REF 2.

MOPT energy monitoring results

The energy monitoring takes control of different energy variables such as: voltage, current, apparent power, reactive power, power factor, power consumption (kWh), temperature and humidity. The power consumption value is cumulative, while the other readings are instantaneous. The analysis of results concentrates on current and power consumption data. The other data can be seen in annexes 5, 6 ,7 and 8[34].

The units of this study were mainly used on weekdays from 08:00 a.m. to 5:00 p.m.. In addition, they are usually used on Saturdays, but no more than six hours. The units are used frequently for many hours in comparison to the units installed in the residential sector. The units are used during the day and in spaces with high presence of people.

Figure 1 shows the differences in the magnitude of the instantaneous current between the four units. It should be noted that the equipment called REF 2 has a cooling capacity of 24,000 BTU/h. Thus, it is not truly comparable with the eco-efficient unit GIZ 2 or the other units. The equipment GIZ 1 and REF 1 are completely comparable by having the same cooling capacity. However, the contrast between the eco-efficient units and the reference units is noticeable. It is reasonable to assume that a reference unit of 18,000 BTU/h would present a contrast of equal magnitude. The same would apply when contrasting a reference unit of the study against an eco-efficient unit of 24,000 BTU/h.

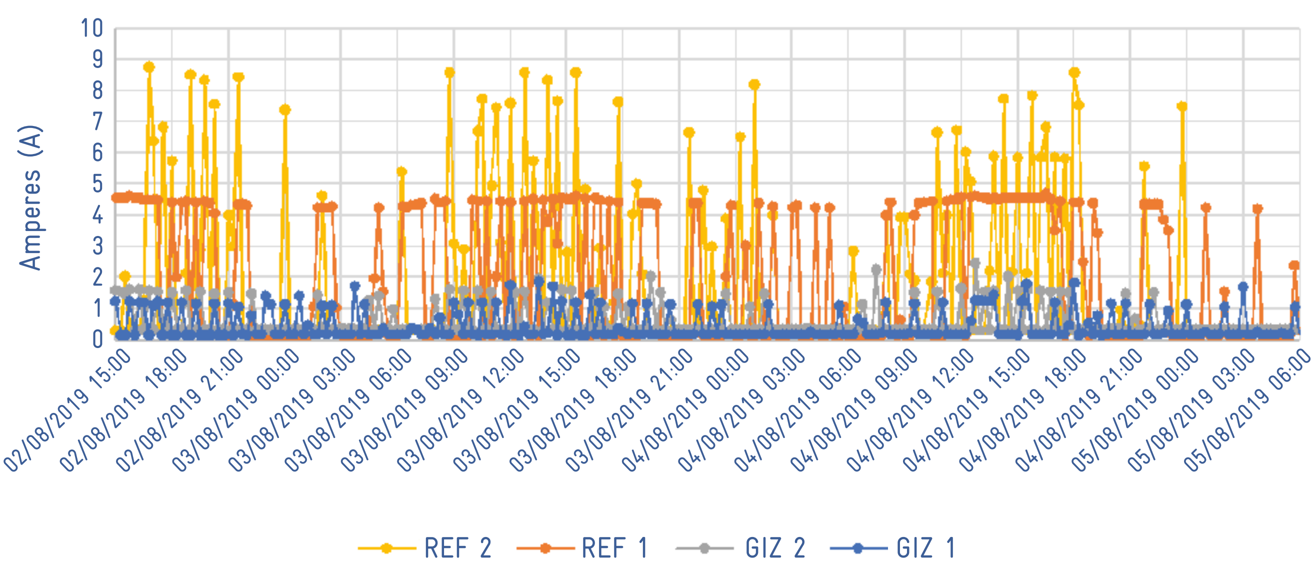

Figure 1. Current against time graph, MOPT energy monitoring.

34 GoMeta (2019): Energy monitoring.

It is clearly visible that eco-efficient units demand a small amount of electricity in comparison to reference units. In fact, there is little difference between eco-efficient units, despite the difference in thermal capacities. The reference units show big differences in their performance: The behaviour of *REF 2* is much more erratic and with higher instantaneous values than *REF 1*, but eventually *REF 1* reported a higher average current. This could mean that *REF 1* requires to be switched on for longer in order to maintain the programmed temperature. The effect of the radiation of the outdoor temperature can also be seen, since less current is recorded at night.

Figure 2 demonstrates the power consumption of the four units. This data is cumulative given the very nature of the unit kWh, so the data collection is restarted at the beginning of the test to record and add from that point. The highest electricity consumption of the reference units is clearly visible in accordance with the current data. An increase in consumption can be seen between 12:00 and 15:00 p.m., the hottest hours of the day. The eco-efficient units show no significant alteration during the hottest hours of the day. These units manage to maintain a more constant electrical demand. It is also visualized that the *REF 1* unit consumes more energy than the *REF 2* unit, which is to be expected since it has presented a higher amount of current during the test. This possibly means that the REF 1 unit is used more frequently than the *REF 2* unit. Again, the difference between eco-efficient units is small, and a comparison with the reference units shows a large difference

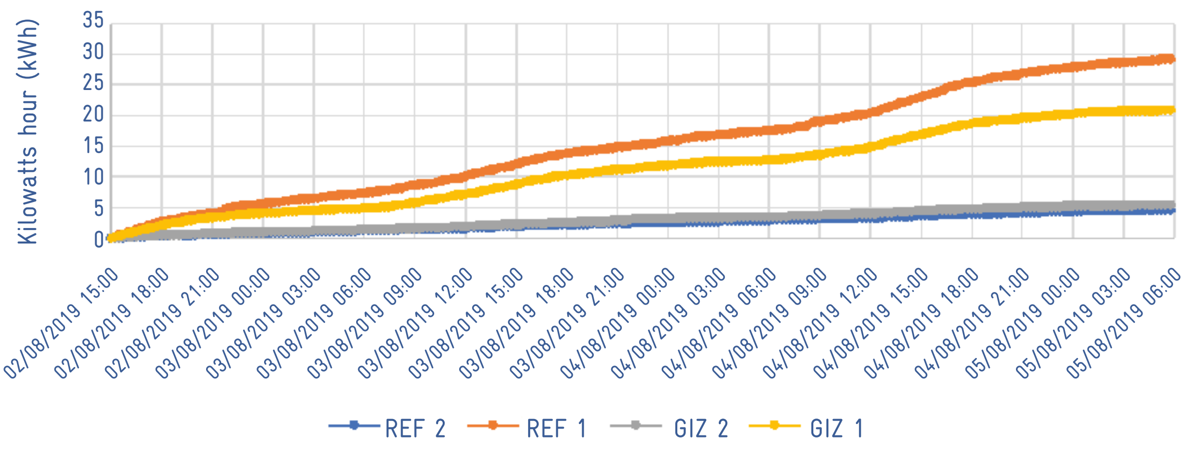

Figure 2. Graph of energy consumption against time, MOPT energy monitoring.

Table 6. Average Intensive Test Data, MOPT

Unit	Average current (A)	Total electricity consumption (kWh)	Average power (kW)
GIZ 1 Godrej 12k BTU Inverter	0.46	4.66	0.07
REF 1 Samsung 12k BTU	2.06	29.30	0.47
GIZ 2 Godrej 18 k BTU Inverter	0.60	5.44	0.09
REF 2 [35] Innovair 24k BTU Inverter	1.34	15.70	0.25

Table 6 summarises the average data of all the current readings, the total electricity consumption after 63 hours, and the average power data, i.e., the electricity consumption divided by the hours, of all monitored units. The average power data reflects the amount of energy of the electrical current used per second in this equipment when considering the nature of the use, the moments of highest demand and those when it operates in a leisure or inactive state. A great difference is visualized between the eco-efficient units and the reference units. These numbers are not completely comparable, since the *REF 2* unit has a cooling capacity of 24,000 BTU/h. However, the results provide a clear indication of the possible energy savings when using an eco-efficient unit.

As part of the collaboration with the MOPT, it has been planned to carry out an upscaling strategy. First, an inventory of existing AC units considering the environmental impact will be prepared. Second, good practice standards will be established, to promote environmentally friendly consumer habits. Finally, a plan will be developed to dismantle the equipment and replace it with eco-efficient ACs.

Apart from the intensive testing, data has been collected from the units since the time of installation presented in Annex 9. It should be noted that the daily electricity consumption of the 12,000 BTU/h eco-efficient Inverter units was 1.16 kWh (a saving compared to the reference units of the same capacity of 72.04%), while the eco-efficient 18,000 BTU/h units had a daily electricity consumption of 1.72 kWh with a saving of 17.44%[36] when compared to the *REF 2* Inverter unit.

The values presented can vary greatly, as the energy consumption and efficiency of an AC equipment depends largely on the habits of users, size of the room, presence of windows, latitude, and orientation to the sun. In Annex 10, the calculations for the theoretical savings according to the SEER efficiency of the equipment are summarized. Using eco-efficient units of 12,000 BTU/h could mean an average saving of 21.06%, while using eco-efficient units of 18,000 BTU/h could mean an average saving of 30.77%, both comparisons against the reference units shown in Table 5.

Hotel Ambassador

In the Hotel Ambassador, located in Paseo Colón, San José, a total of 20 eco-efficient AC units were installed. The energy monitoring devices were installed at 18 imported units and at existing conventional units in the building selected as reference. In addition to the long- term monitoring, the intensive study was realized for 26 hours.

35 The data of MOPT 2 has been corrected by a factor of 25%, given that it is a unit with a thermal capacity of 24,000 BTU/h. The aim is to simulate the values of a unit of 18,000 BTU/h.
36 Ibid

Table 7. Main characteristics of the AC equipment under study.

Unit	BTU/h	Coolant	Tech-nology	Effi-ciency
GIZ 1 Godrej[37]	12,000	R-290	*Inverter*	20,86 BTU/Wh REEE
REF 1 Carrier[38]	13,500	R-22	Conven-tional	3.12 EER 10.63[39] SEER

The test began on Monday, July 29, 2019, around 3:00 p.m. and ended on Tuesday, July 30, at 7:00 p.m. The units operated in empty rooms of similar size with closed doors and windows. Moreover, neither room had a wall or window in direct contact with the outside of the building. The target temperatures (20°C) of the units were programmed so that the room temperature would be below the average outside temperature.

Room 211 contained an approximately 20-year-old Carrier window AC unit. This unit does not have an accurate digital thermostat, so the configuration detailed in the image below was used. By means of temperature measurements (Dallas and infrared sensors) it was determined that this configuration is approximately equivalent to a temperature of 20 °C.

Photo 13. Carrier AC reference team from the Hotel Ambassador.

37 General specifications of the Godrej units in Annex 2
38 The unit is conventional window type. They are normally used for about six hours, when there are guests in the room.
39 Estimated data. It should be mentioned that calculating the SEER value for a conventional unit (fixed speed), is exceedingly difficult. This value is only an approximation.

Photo 14. AC R-290 GIZ 3 equipment.

Photo 15. Hotel Ambassador in Paseo Colón, San José.

Results

Room 209 with the eco-efficient unit took several hours to reach an equilibrium temperature due to unknown factors. Therefore, slightly outdated time intervals are compared below. It is not considered that this affected the obtained data in a significant way. The graphs with all monitoring variables can be seen in Annexes 11 and 12[40].

The units are not used regularly but are extensively used when needed. It is not uncommon that guests handle the equipment carelessly, set low temperatures or keep the unit running when they leave the room.

Figure 3 clearly shows that the *REF 3* unit requires more electrical current to maintain the target temperature of the room. It was previously mentioned that the GIZ 3 eco-efficient unit reached the target temperature with a time delay due to unknown reasons. It is suspected that the initial conditions of the room may have been different from those of the room with the *REF 3* unit. Evidence of this is that the current curve of the *GIZ 3* eco-efficient unit maintains an almost constant value from the beginning of the test until around 01:00 p.m. on the 30th. From this moment on, the current curve denotes mostly idle operation, interspersed with periods of operation. These operating periods coincide in broad terms with the operating periods of REF 3 unit. It is also noted that REF 3 has a greater leisure current.

Figure 4 compares the power consumption between the two units. As expected according to the electric current data, the *REF 3* unit consumes more than the *GIZ 3* unit. It is possible to detail a decline in the consumption curve of the *GIZ 3* unit, which coincides with the time of temperature stabilisation

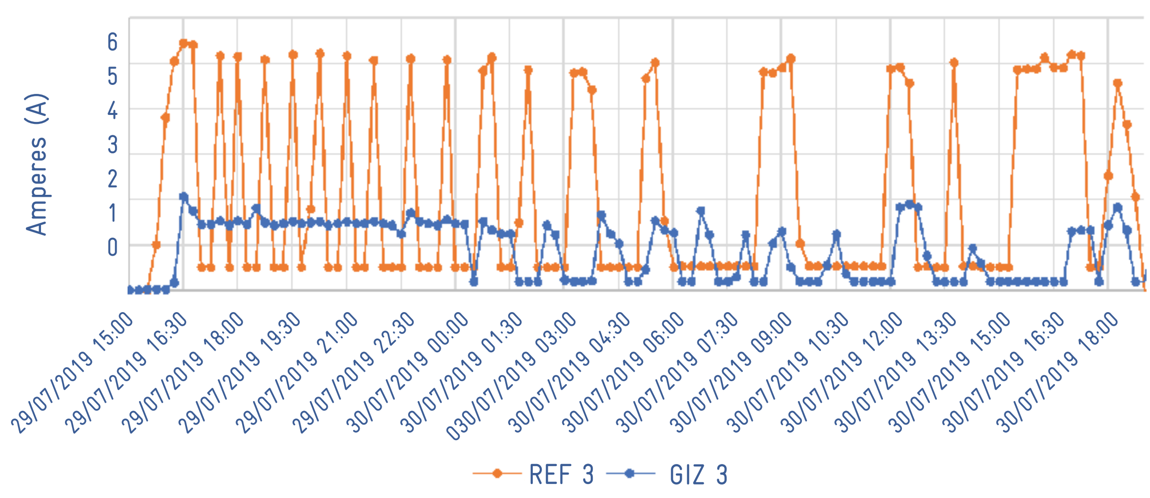

Figure 3. Current against time graph, energy monitoring Hotel Ambassador.

40 GoMeta (2019): Monitoreo energético.

and operation determined in the electric current curve. The *REF 3* curve is maintained with a constant slope operating in a similar way during the whole test. The curves seem to indicate that these units were not affected by the temperature increase during the day. The alternate behaviour between active and idle operation was maintained. This can be explained by the location selected to carry out the tests, avoiding the incidence of solar radiation. It can be observed that both rooms offered similar conditions.

Table 8. Average data for intensive test, Hotel Ambassador.

Unit	Average current (A)	Total electrical consumption (kW h)	Average power (kW)
GIZ 3 Godrej	0.91	4.79	0,.18
REF 3 Carrier	1.90	12.63	0.49

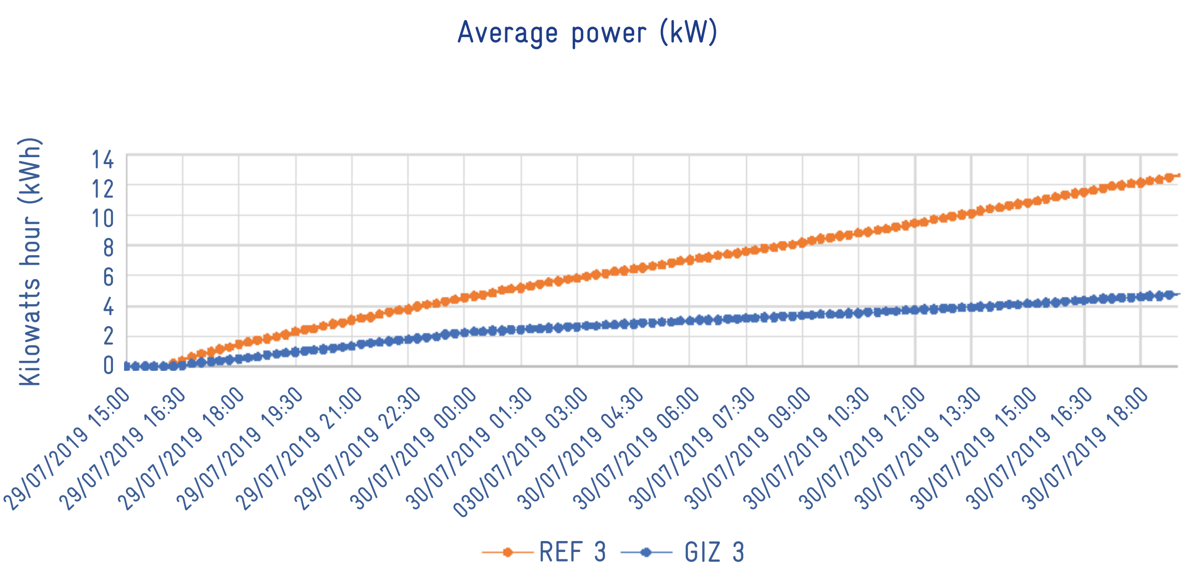

Figure 4. Graph of electricity consumption against time, energy monitoring Hotel Ambassador

The average electrical consumption measured for the units differ greatly, as also shown by the results from the intensive test in the MOPT. In table 8, two points should be highlighted. First, the power of the *GIZ 3* unit is a little more than double the power of *GIZ 1*, even though they are the same model. However, a significant difference from the reference unit was maintained. Secondly, *REF 3* and *REF 1* have an almost identical average performance, which suggests that those units had similar wear and tear.

At the Hotel Ambassador, 20 eco-efficient units and 18 energy monitoring devices were installed. The historical data of all the units monitored at the Hotel Ambassador can be seen in Annex 13. When comparing the 12,000 BTU/h eco-efficient units with the Carrier units, a difference of 63.87% in daily electricity consumption (kWh) is found. The daily electricity consumption of the eco-efficient units was 1.10 kWh. Furthermore, two 18,000 BTU/h eco-efficient units were placed in the hotel's conference rooms. Both had a daily consumption of 2.57 kWh, which is higher than the eco-efficient units installed in MOPT. As it is a large room and not an office, the use required more energy and a higher capacity for more consecutive hours. Annex 14 shows the theoretical estimate of savings amounting to 39.47%, compared to units of the same capacity installed in Hotel Ambassador.

Costa Rican Electricity Institute (ICE)

The public electricity company of Costa Rica (Instituto Costarricense de Electricidad - ICE) received 20 eco-efficient units. ICE was interested in carrying out its own monitoring program, and the information from this project is not yet available. However, smaller-scale monitoring was carried out in collaboration with GIZ. Two eco-efficient units were installed at ICE's Energy Efficiency Laboratory with both cooling capacities. The units were put into operation non-stop for several days in a row and for longer periods of time.

Photo 16. Eco-efficient unit with a capacity of 12,000 BTU/h (left).

Photo 17. Condensing unit of the 18 000 BTU/h eco-efficient unit.

Table 9. Main characteristics of the AC equipment under study.

Unit	BTU/h	Coolant	Tech-nology	Effi-ciency
GIZ 1 Godrej[41]	12,000	R-290	*Inverter*	20.86
GIZ 5 Godrej	18,000	R-290	*Inverter*	20,.86
REF 4 Comfort star[42]	12,000	R-410A	*Inverter*	15.00

When the energy monitor was installed in the *REF 4* unit, it was connected only to the indoor unit, i.e. the evaporator, and its associated circuits, the information panel (LED lights) and fans. Therefore, the vast majority of the energy consumption, such as the consumption of the condensing unit, was not measured by this monitor. Both units were installed in the calibration laboratory and programmed at a temperature of 23 °C.

Results

Table 10. Historical data on eco-efficient units.

BTU/h	Days	Average current (A)	Total electricity consumption (kWh)	Daily electricity consumption (kWh)
12,000	21	0.31	14.60	0.70
18,000	22	0.65	44.10	2.00

The units have been used in different ways. Continuous use without complete shut down over entire days has predominated. These units always operated at the programmed temperature. The units were used in different periods of time.

Two units have been installed and put through nonstop use over several days of continuous operation under laboratory conditions. The eco-efficient units withstood the tests, neither failed nor overheated, and behaved similarly to the reference equipment.

The monitoring process was also facing a few challenges. Access to the ICE internet network was not granted, so an additional Wi-Fi router was provided. The energy monitoring devices have no internal memory, so information not sent due to the lack of connection has been lost. However, there are plans to resolve these issues and carry out better and more ambitious tests in the future.

Other R-290 AC demonstration sites

The energy monitoring devices were also installed on units donated to other institutions. The monitored units were used in different ways and under different conditions. The historical values of consumption are observed and analysed, providing information and evidence on the operation of the eco-efficient units. The buildings where the units were placed belong to institutions dedicated to the protection of the environment and its ecosystems. Given this reason, the units were used with great precaution, only for activities or in moments that were necessary, and not for a long time. This made it difficult to isolate a representative and comparable pattern of behaviour.

41 General specifications of the Godrej units in Annex 2.
42 Split type inverter unit previously installed in the laboratory. This specific room requires the equipment to be used throughout the day.

Table 11. Monitored units.

Eco-efficient unit[43]	Location	BTU/h
GIZ 5	DCC	18,000
GIZ 6	DIGECA	18,000
GIZ 7	MINAE	18,000
GIZ 8	MiTransporte GIZ	18,000
GIZ 9	MiTransporte GIZ	18,000

The monitored units were used in meeting rooms without any planned experiments. No reference units were contemplated since there was no AC equipment in those spaces previously or all the AC units in the buildings were already eco-efficient and operated with the refrigerant R-290. A table with the historical summary of several variables in the use of each unit is included in Annex 15.

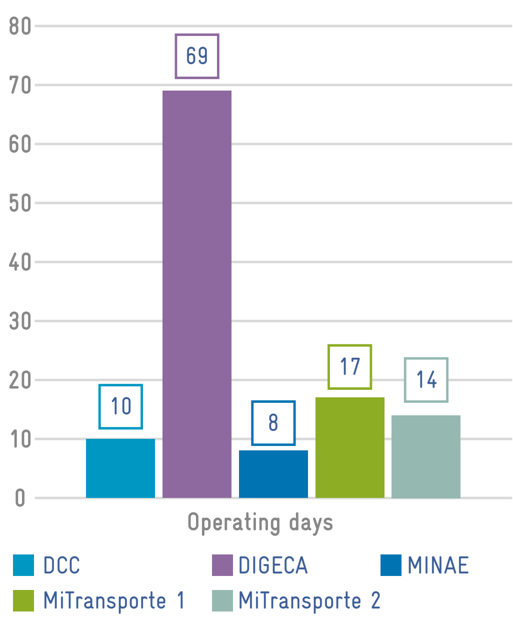

Figure 5. Total days of use of each eco-efficient unit.

Figure 5 shows that the GIZ 6 unit, installed in DIGECA's offices, has operated more days than the other units. The units are generally located in meeting spaces. Therefore, it is unusual that the units are used in a continuous way. In cases of use, it would be for a short period of time and not for a whole working day. All units are more than one year old: GIZ 5, GIZ 8 and GIZ 9 were installed in December 2018; GIZ 6 and GIZ 7 in April 2019.

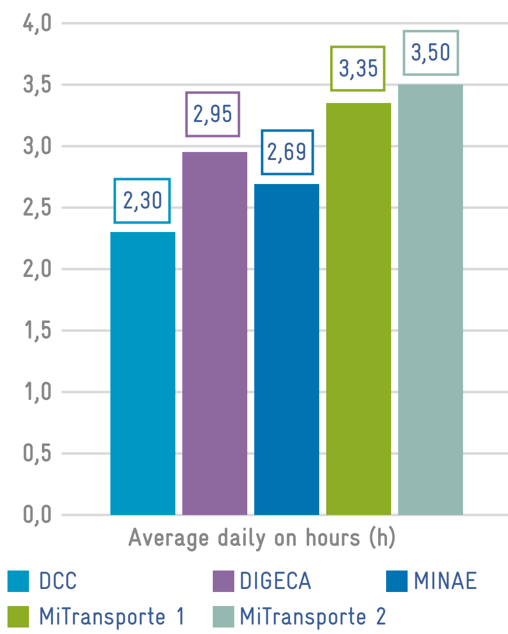

Figure 6. Average hours of daily operation for each eco-efficient unit.

By means of the energy monitoring, an estimate of the daily running time of each unit can be made. This is done by using the average current. This parameter sets a limit value that defines whether the unit is switched on or off. This does not work with other units, such as reference units since the behaviour of the equipment and the average current in the idle state are different. For Figure 6, the limit of operation was defined as 2.5 A, higher than the leisure current or "standby". It is observed that the units were normally used between two and four hours.

43 General specifications of the Godrej units in Annex 2.

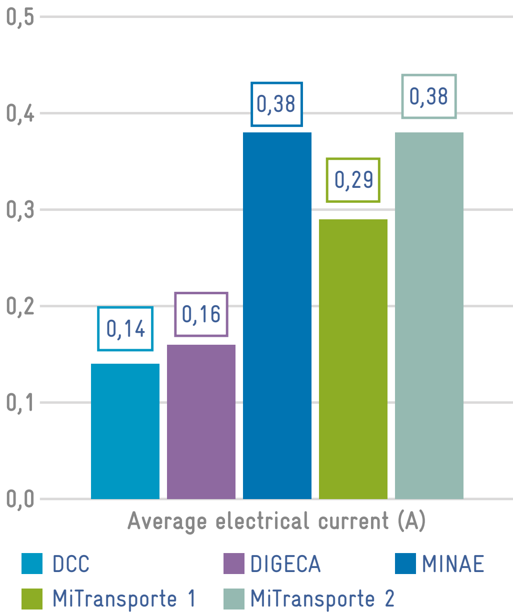

Figure 7. Average electrical current required in the use of each eco-efficient unit.

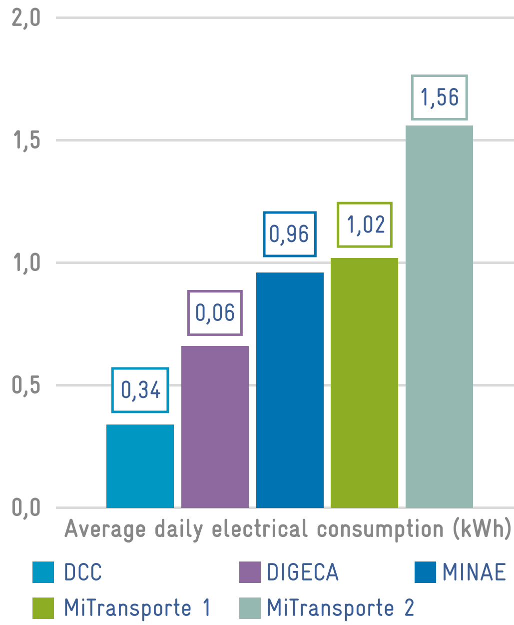

Figure 8. Average daily energy consumption of each eco-efficient unit.

Figure 7 provides an idea how the units were used. It is noted that *GIZ 9* required a higher amount of average current to meet the ambient and scheduled operating conditions. For example, setting a low temperature when it is hot outside the room or building, or using the unit while having a window open in the room.

As demonstrated in Figure 8, the *GIZ 5* unit operated with less power consumption as it was turned on for the least number of days and was likely to work under more stable conditions. These factors influenced the unit to be the most efficient. In addition, it should be noted that the *GIZ 9* unit required the most energy corresponding to the fact that the unit was used the most working hours per day. The high energy consumption from *GIZ 9* as well as from *GIZ 8* can be attributed to their location in a large room used for events.

Energy monitoring conclusions

It is evident from the analysed data that eco-efficient units consume less energy, operate with less current in both active and idle states and respond better to changes of external temperature.

Table 12. Summary of intensive tests[44].

Unit	Average current (A)	Electrical consumption (kWh)	Average power (kW)
GIZ 1 MOPT	0.46	4.66	0.07
REF 1 Conventional MOPT	2.06	29.30	0.47
Difference %	77.67	84.10	85.11
GIZ 2 MOPT	0.60	5.44	0.09
REF 2 Inverter MOPT	1.34	15.70	0.25
Difference %	55.06	65.34	63.64
GIZ 3 Hotel Ambassador	0.91	4.79	0.18
REF 3 Window Hotel Ambassador	1.9	12.63	0.49
Difference %	52.11	62.07	63.27
AVERAGE DIFFERENCE	61.61	70.50	70.67

Table 12 summarises the differences between the units evaluated in the intensive test. Although the units are not strictly comparable with their varying thermal capacities, except from the first case, the data provides an approximate idea of the possible energy savings when using an eco-efficient unit. In the three contrasted cases, the power and electricity consumption were twice and up to four times lower than the eco-efficient units.

Table 13. Comparison of historical data against intensive studies regarding daily[45] electricity consumption.

Location	BTU/h	Intensive testing	Historical Data	Average
MOPT[46]	12k	84.10%	72.04%	78.07%
MOPT[47]	18k	65.34%	17.44%	41.39%
Amba-ssador[48]	12k	62.07%	67.87%	62.97%
Promedio	14k	**70.50%**	**51.12%**	60.81%

Table 13 shows the comparative results of the two data sources: the intensive tests at MOPT (63 hours) and at the Hotel Ambassador (26 hours), and the historical data of all units with corresponding thermal cooling capacities. To account for different technologies, units of the same type were contrasted regarding their historical data and in the intensive tests. In MOPT, the 12,000 BTU/h units of reference are of conventional technology, and the 18,000 BTU/h unit is an Inverter-type unit. In the Hotel Ambassador the reference units are all Carrier window-type equipment.

Energy monitoring is difficult to carry out as every unit is used in different ways. Therefore, the intensive tests were carried out in a manner to ensure that the equipment is being used in the same way. However, the ACs do not run continuously all day, and neither is this type of operation recommended. Therefore, the data from the intensive tests was compared with the historical data (see Annex 16). The daily electricity consumption varies considerably between these two types of data, but the percentage differences have not changed significantly. The average of both data is used as it considers the identical (in the intensive test) and varying daily use of the equipment. It should be noted that in both types of

44 The differences in this table refer to the percentage difference from the reference unit. For example, the GIZ 1 unit consumed 84.10% less electrical current than *REF 1*.
45 Historical data information in Annexes 9 and 13.
46 *REF 1* against GIZ 1 for the intensive test. The historical data considered all 12,000 BTU/h units of conventional technology installed in MOPT, Godrej units and previously installed units.
47 *REF 2* against GIZ 2 for the intensive test. The historical data considered all 18,000 BTU/h units of *Inverter* technology installed in MOPT, Godrej units and previously installed units.
48 *REF 3* against GIZ 3 for the intensive test. The historical data considered all 12,000 BTU/h window technology units installed at the Hotel Ambassador, Godrej units and previously installed units.

data there is a greater difference between the eco-efficient compared to the conventional unit, than compared to the window type units. This result is due to the complexity of obtaining data with similar conditions. In the intensive test, the eco-efficient unit took a particularly long time to stabilize the temperature. This reduces the difference gap of the energy consumption of the Carrier unit. The historical data shows that the eco-efficient units were used on average 31.07 days, while the Carrier units were used 22.67 days (see Annex 16). Ideally, they would have been used with a similar number of days. It is to be expected that the difference would be greater than with the conventional unit.

Despite the differences in use, number of days and hours per day and the eventualities of intensive testing, the large amount of historical data offers robustness to the results and confirms to some extent the values of the intensive tests. An exception is the comparison in MOPT with units of 18,000 Btu/h since they are Inverter-type units. It can be conservatively estimated that there is a difference in electricity consumption of at least 40% between the conventional technology equipment installed in the MOPT and Hotel Ambassador and an eco-efficient unit with R-290.

It is recommended that manufacturers of AC equipment include energy monitoring devices as part of each AC unit from the factory. Many devices already have built in Wi-Fi, which would serve as a means of data transmission. A preliminary study estimates the additional cost of production at approximately less than $10 per unit. These sensors must be able to transmit collected data through a standardized protocol (e.g., MQTT) to a configurable server. This would allow to create a very wide network of energy monitoring on an international level at low cost. If it is not possible to incorporate sensors in the manufacturing factory, it is recommended to develop a standardized external sensor for the same purpose.

There is a high interest in the possibility of being able to control AC equipment in an intelligent way. In a hotel, the reception could remotely turn on the AC before the guest enters his room and turn off the AC when the guest leaves the hotel. This could lead to significant energy savings without impacting the guest's experience. Other hotels expressed interest in the possibility of charging guests for excessive energy consumption. This approach could perhaps be incorporated into an "ecotourist" program, where users are encouraged or at least made aware of the energy consumption impact of their actions.

It is also recommended to define a standard statistical scheme for evaluation and comparison of energy monitoring. In this way, energy monitoring can be scaled up and the results between different versions would be verifiable.


NXW

OPERATING COSTS AND MONETARY SAVINGS

Eco-efficient units have shown lower energy consumption. In this project the operation of these units has been compared against units of different types. The costs and monetary savings are then compared against these types of AC equipment.

In Table 14[49] ICEs[50] commercial rate was used. According to estimates for our latitude and climate zone, it is assumed that an equipment on average is used around 1,951 hours per year[51]. This usage would represent the potential use of these units, however both the MOPT and Hotel Ambassador units were used fewer hours per year. According to estimates made with the energy monitoring, these units could operate around 800 hours on average per year. Therefore, the estimated calculation uses this data.

Based on the investment cost of an *Inverter* unit with R-290 ($600 for 12,000 BTU/h and $800 for 18,000 BTU/h), the average investment could be recovered in 10 years by the estimated savings when replacing a conventional split or window unit. In the case of the window unit, it has been explained that greater savings in electricity consumption and thereby greater monetary savings can be expected. Generally, the equipment is old and uses refrigerants such as R-22, that are being phased-out[52]. The saving of an eco-efficient unit when compared to a split inverter unit should encourage consumers, to replace their old ACs and acquire an eco-efficient unit.

The cost calculations set out in Table 14 are not the total and true costs. The rates used represent only the charge for energy consumption (kWh). Therefore, savings are even greater. It is necessary to consider the charge for power consumption (kW) and to classify the volume of energy consumed by type of building, since there are differentiated rates above a certain limit for consumption[53]. Therefore, operational costs are sufficient to cover the investment of an eco-efficient unit if 1,951 hours per year are used (estimated according to the latitude and climate of Costa Rica). However, in the case of 800 hours of use per year the obtained data showed that the investment is only recovered when comparing the eco-efficient units against the

Table 14. Potencial monetary savings of eco-efficient units against other types of units.

Comparison	BTU/h	Daily energy consumption (kWh)	Energy consumption in a potential year (1,951 hours) (kWh)	Savings in a potential year (1,951 hours), commercial rate ($)	Potential 10-year savings (1,951 hours), business rate ($)	Energy consumption in an estimated year (800 hours) (kWh)	Savings in an estimated year (800 hours), commercial rate ($)	Estimated 10-year savings (800 hours), business rate ($)
R-290 inverter and conventional window	12,000	1.10	351.08	119.26	1,192.59	148.11	50.31	503.12
R-290 inverter and conventional split	12,000	1.16	371.07	263.80	2,637.98	156.54	111.29	1,112.90
R-290 inverter and split inverter	18,000	1.72	550.15	77.60	775.99	232.10	32.74	327.37

49 The comparisons and percentages of average electricity consumption savings according to Table 13 were used.
50 ICE, 2020: Electricity rates for the year 2020.
51 UNEP, 2019: Energy – Efficient and Climate – Friendly Air Conditioners. MODEL REGULATION GUIDELINES; MINAE (2019) Greenhouse Gas Inventory for Refrigeration and Air Conditioning for Costa Rica (2012-2016) (in Spanish).
52 EPA: Phaseout of Ozone – Depleting Substances (ODS).
53 For example, at commercial rates, each kWh below 3,000 kWh costs ¢116.15. Each kWh above 3,000 kWh is charged at ¢69.50.

conventional window and split units. It should be noted that there is a considerable saving when comparing the eco-efficient against the split Inverter unit, although not enough to cover the investment. but it is significant and should be considered when replacing a conventional unit by a new one.

Table 15. Potential and estimated monetary savings at participating institutions when changing AC units.

Location	BTU/h	Potential units to be replaced	Potential savings in one year, commercial rate (1,951 hours) ($)	Estimated savings in one year, commercial rate (800 hours) ($)
Ambassador[54]	12,000	15	1,788.88	754.68
Ambassador[55]	18,000	5	388.00	163.69
MOPT[56]	12,000	8	2,110.39	890.32
MOPT[57]	18,000	12	931.19	392.85

The *Inverter* technology with R-290 can also be compared by looking not only at the operational costs, but also by looking at the costs of installation, maintenance, electricity bill and efficiency. The following is a theoretical comparison of the Inverter technology with conventional refrigerant against the same technology with natural refrigerant R-290.

Table 16. Theoretical economic comparison of eco-efficient units against market units (1,951 hours/year).

	12,000 BTU/h		18,000 BTU/h	
Coolant	R-410A	R-290	R-410A	R-290
Typical use (rate)[58]	Residential and commercial		Residential and commercial	
Capacity (kW)	3.5	3.5	5.3	5.3
SEER (BTU/Wh)	19[59]	20.86	19[60]	20.86
Annual electricity consumption (kWh)	1,232	1,123	1,847	1,684
Annual electricity bill ($)	270.88	246.88	406.32	370.32
Energy saving of eco-efficient unit (%)	-8.86%		-8.86%	
Potential 10-year savings (US$)[61]	267.69		401.33	
TIR	38.19%		44.61%	

In Costa Rica, by 2019, most AC split type units with Inverter technology in the market had an average SEER of 19 BTU/Wh. Table 16 summarizes two financial calculations: the theoretical calculation of savings according to efficiency and the internal rate of return (IRR). The most present model in the market is then compared against imported eco-efficient units. Imported units have a higher added value when operating with a different refrigerant, so they have a higher investment cost. However, in 10 years, it is more profitable to acquire an eco-efficient equipment considering the higher costs for energy as well as installation and maintenance. Therefore, if an AC unit needs to be renewed, it should be replaced with an eco-efficient unit.

54 Comparison R-290 Inverter and conventional window, according to Table 14.
55 Comparison R-290 Inverter and split Inverter, according to Table 14.
56 Comparison R-290 Inverter and conventional split, according to Table 14.
57 Comparison R-290 Inverter and split Inverter, according to Table 14.
58 We used the average residential tariff above 200 kWh from ¢139.00, and the commercial tariff below 3,000 kWh from ¢69.50.
59 GIZ, 2020: Market study on energy efficiency of AC split type in Costa Rica.
60 Ibid.
61 Only theoretical differences are considered because of the efficiencies of the equipment. It is necessary to consider the use and maintenance.
62 GIZ, 2020: Market study on energy efficiency of AC split type in Costa Rica.

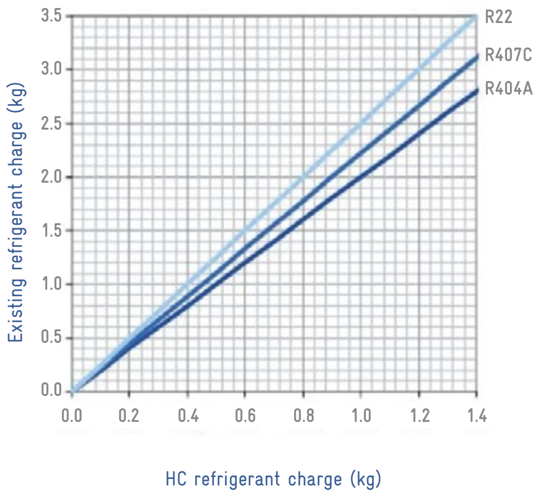

Figure 9. Conversion from conventional refrigerant charge to estimated equivalent hydrocarbon refrigerant charge (e.g. R-290)[63].

Maintenance costs were considered in the same way and at the same price. However, maintenance costs are lower for AC equipment with R-290 as they have a lower incidence of leakage. As propane is a more efficient substance, it requires less charge than conventional refrigerants (see Figure 9). On the one hand, it is projected that the prices of conventional refrigerants (e.g., R-22 and R-410A) will increase and that the use of quotas allowed per year, and sometimes imposed, will be implemented to discourage the use of these substances. This is part of the global and national commitments to reduce environmental impact, such as the Montreal Protocol and the NDC (Nationally Determined Contributions)[64]. On the other hand, natural refrigerants are promoted. It is expected that in the medium term the Latin American region will follow this trend.

However, the economic and environmental costs of AC equipment using HCFC and HFC refrigerants, which are ODS and high GWP substances, were not considered. In addition to these emissions, the costs of refrigerant recovery, storage, and logistics of testing and destruction of old refrigerants were also not taken into account.

63 GIZ Proklima, 2011: Operation of Split Air Conditioning Systems with Hydrocarbon Refrigerant.
64 European Environmental Agency, 2019.

MITIGATION POTENTIAL

Currently the presence of environmentally friendly and eco-efficient AC units in Latin America is extremely low. In many countries the technology has not formally entered the market and, in those countries more advanced in this area, R-290 units have a small market share. The project described above has been one of the most ambitious efforts in the region in pursuit of that goal. Most of the available technologies use ozone-depleting refrigerants (HCFCs) or HFC refrigerants as alternatives, which do not damage the ozone layer but do have a high GWP and major negative climate impact. Despite the high production of electricity from renewable sources in Costa Rica, an AC unit emits about 3.7 tons of CO_2eq throughout its lifespan (10 years)[65]. Currently there are 300,000 AC units in Costa Rica and sales are increasing. The Refrigeration and Air Conditioning sector (RAC) was responsible for approximately 12% of the Greenhouse Gas (GHG) emissions in 2012[66]. The Costa Rican government has ambitious climate plans and has implemented a system to recognize companies and organizations with correct management of their GHG emissions[67]. To achieve this goal, it is necessary to move to refrigerants with ultra-low GWP values, such as natural refrigerants (R-290).

Figure 10 shows the projection of GHG emissions according to three different scenarios. The BAU (Business-As-Usual) scenario represents the situation if the industry follows the same course it has taken. The MIT scenario: REF (Mitigation and Refrigerants) illustrates the case where mitigation measures are applied and a transition to natural refrigerants such as R-290 occurs. Finally, MIT: REF+EE adds the use of highly efficient equipment to the previous scenario. The accumulated mitigation potential, for the MIT: REF scenario, up to 2050 for the unitary AC sub-sector is 4.52 megatons of CO_2eq. Additional savings in emissions can be achieved by increasing the deployment of highly energy efficient Inverter equipment.

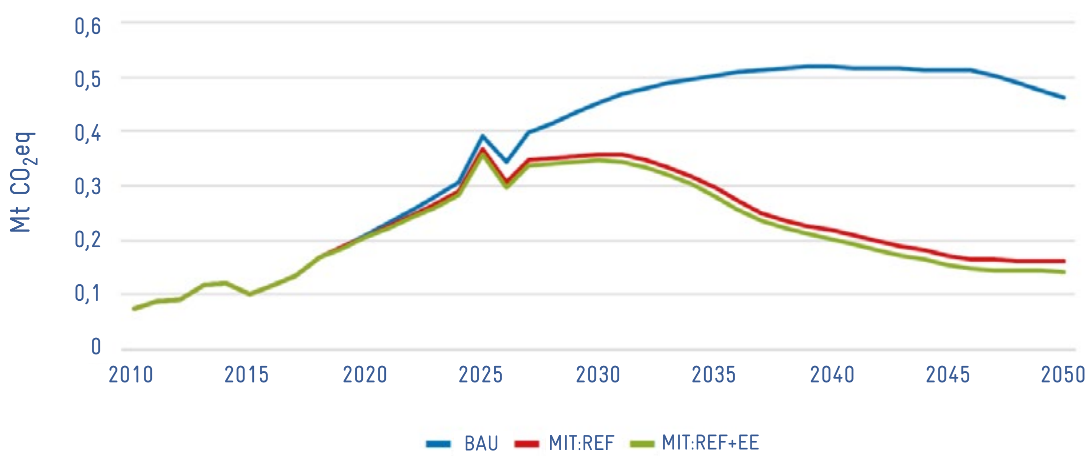

Figure 10. Projected GHG emissions for unitary air conditioning, years 2010 - 2050.

65 According to 13% average refrigerant leakage rate per year in Costa Rica in AC split type equipment based on, GIZ, 2020a: Leakage study in split type air conditioning equipment in Costa Rica.
66 MINAE, 2019: Refrigeration and Air Conditioning Greenhouse Gas Inventory for Costa Rica (2012-2016).
67 DCC, 2018: Carbon Neutral Country Program version 2.0.

An eco-efficient unit has an average mitigation potential of 2.2 tons of CO_2eq compared to a conventional unit over its lifetime (ten years), considering both direct emissions (related to the refrigerants used) and indirect emissions (emissions from electricity generation).[68]

Table 17. Comparison of emissions between R-410A and R-290 and mitigation potential.[69]

Up	R-410A Inverter unit (1,951 hours per year)	R-290 Inverter unit (1,951 hours per year)
Indirect emissions (tons CO_2eq)	1.5	1.5
Direct emissions (tons CO_2eq)	2.2	0.001
Total emissions (tons CO_2eq)	3.7	1.5
Mitigation potential (tons CO_2eq)	0	2.2

In other countries with higher grid emission factor[70] and leakage rates, the difference between conventional and eco-efficient units could be up to ten times greater. The eco-efficient units used under this project, and other models that are internationally available, are being designed with high efficiency ratings (SEER). Thus, these eco-efficient units provide energy and monetary savings.

Due to the high level of electricity generation from renewable sources in Costa Rica[71], there is a low emission factor from the electricity grid, so indirect emissions are already quite low. The best approach would be to mitigate direct emissions. Conventional refrigerants such as R-22 and R-410A have quite high GWP values of 1,760 and 1,923 respectively, while R-290 has a GWP value of only 3[72].

68 According to 13% average refrigerant leakage rate per year in Costa Rica in AC split type equipment based on, GIZ, 2020a: Leakage study in split type air conditioning equipment in Costa Rica.

69 Estimated calculations when considering a unit of 18,000 Btu/h with a load of 0.85 kg, with leaks from: installation (2%), annual rate (13%) and at the end of its useful life (95%). This results in 2.2 tons CO_2eq direct emissions with R-410A and less than 15 kg with R-290.

70 In $kgCO_2/kWh$, it refers to the associated emissions in the generation of electricity for an electrical network.

71 Presidential House, 2019: For the fifth consecutive year, Costa Rica will exceed 98% of renewable electricity generation.

72 IPCC, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Photo 18. Godrej condensing unit installed at the ICE Energy Efficiency Laboratory.

SCALING-UP STRATEGY

As previously described, AC split type equipment is hardly available in the Latin American market. In fact, manufacturers are usually from China and India (like the imported Godrej units). This project has been a successful demonstration of a significant number of units being implemented. In addition to the donated units, four national training institutions received equipment, necessary tools, and the corresponding training to offer courses on natural refrigerants. This expertise acquired by the training institutes will generate a multiplier effect. A total of 98 participants from 11 countries took part in the trainings. This provides a good basis and a potential multiplier effect when developing scale-up strategies in the region. A mitigation strategy and the inclusion of the RAC sector within the NDC are also being prepared[73]. Additionally, MINAE and GIZ have prepared a proposal to the Green Climate Fund (GCF)[74] to prepare the implementation of the Kigali Amendment of the Montreal Protocol. There is much interest in eco-efficient AC units and other countries are interested in starting their own training and AC introduction programs with R-290.

Several events have been held that have advanced the conversation on the environmentally friendly approach in the RAC sector. In 2019, the workshop "Contributions to the national goal of decarbonization of the Costa Rican economy" was held. Relevant companies were invited for a demonstration of eco-efficient equipment and the units were officially donated[75]. The "Technology Roadshow on Natural Refrigerants" was also organised[76]. Under this event GIZ and DIGECA introduced the AC equipment with R-290 to policy makers and industry representatives from 17 countries.

These events and the effort of this project have prepared the landscape and increased the general knowledge about these alternatives. An objective is to develop an inventory of AC equipment in MOPT, which is followed by a replacement strategy using eco-efficient units. MOPT also intends to carry out a more ambitious and long-term energy monitoring. The collected data can be used to better define the energy savings and to identify practices that have an impact on higher electricity consumption.

The intensive study of energy monitoring is pending at ICE. There are also plans to carry out energy efficiency tests in addition to long-term energy monitoring similar to the monitoring to be carried out at MOPT.

Many other institutions and companies have shown great interest in AC technology with R-290. However, the present implementation project has not been able to establish a supply chain. This task is planned within the GCF project mentioned above, as well as to solve the frequency compatibility between the nominal frequency of the equipment and the frequency of the electric supply in Costa Rica.

In light of recent events, it is anticipated that in the near future the implementation of AC units with R-290 will be much more progressive. Finally, this type of unit entered the market in Europe, specifically from the manufacturing supplier, Midea, from China. This equipment was the only one that won the strict German ecological seal "Blue Angel"[77]. There are also other companies such as ElectriQ, which is one of the largest traders in electrical accessories and equipment in the United Kingdom already selling AC split units with R-290[78]. In Colombia, the company Thermotar is also making progress. It has designed various equipment as central AC (condensing units, package units, chiller and cassette) operating with R-290. In the short term, the intention is to develop AC split type equipment with this refrigerant[79]. In addition, certain measures have already been prepared and implemented to encourage the entry of more AC units with R-290. The European EU F-Gas regulation prohibits the use of HFC refrigerants with GWP values above 150 in portable AC devices from the year 2020. There are at least eight manufacturers of R-290 ACs. Hundreds of thousands of portable R-290 AC units have been sold. It should

73 UNFCC: NDC Spotlight.
74 Green Climate Fund: https://www.greenclimate.fund/about
75 DIGECA, 2019b. (web page)
76 DIGECA, 2019c: Technological tour with natural refrigerants. (web page)
77 Hydrocarbons21, 2020: Highly Rated Midea R-290 Room AC Expected in Germany this Year.
78 Electriq, 2020: ElectriQ, 2020: Environmentally friendly smart Wifi controlled wall mounted inverter split air conditioner with heat pump eiQ-12WMINV-V3 12,000 BTU.
79 Thermotar, 2020: Refrigerant R-290.

be noted that more than 600,000 AC units with R-290 refrigerant have been installed without any problems in India since 2009 and about 370,000 AC units with R-290 will be installed in 2020 in China. Under the Montreal Protocol's Multilateral Fund, also AC production lines will be switched to R-290 in the near future. The trend is clear, and it would then be a matter of time before such AC units are available globally.

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CONCLUSIONS

The project described above has been a successful step on the road to implementing environmentally friendly alternatives in the RAC sector. 100 eco-efficient AC split type units, which operate with ultra-low GWP R-290 natural refrigerant and highly efficient with SEER ratings of 20.86 BTU/Wh, were introduced and demonstrated in Costa Rica.

The transition to ultra-low GWP refrigerants may bring additional benefits to the reduction of GHG emissions. Such related benefits include energy and cost savings through improved energy efficiency, local job creation through the use of qualified technicians able to safely install and maintain RAC equipment with climate friendly refrigerants, or local and regional production of natural refrigerants and energy efficient equipment using natural refrigerants.

The training campaign carried out between December 2018 and December 2019 has resulted in 98 trained instructors and technicians trained in the handling of equipment with natural refrigerants. These people are trained in installation and service of refrigerators with R-600a and AC equipment with R-290. The 98 participants came from 11 countries in the region, most from Central American countries. Five percent of the participants were women, which is a higher participation than expected due to the great gender disparity present in the service sector.

Four national training institutes have trained instructors, equipment and supplies necessary to offer courses for the handling of natural refrigerants in the near future, and plans exist to include these issues within their curriculum. Three of these institutes also have received eco-efficient units. This will generate a multiplier effect on the number of people trained on these refrigerants. Training institutes and trainers are showing great interest in this technology. Having a strong base of technicians will greatly facilitate the introduction of these units in the market, since they have a safe and reliable maintenance support. The training campaign is one more piece in the mission to reduce energy consumption and GHG emissions.

The trainings have been developed with the experience of GIZ Proklima, the knowledge of the Godrej company and mainly adhering to international standards on the safe handling of natural refrigerants. Currently, GIZ and DIGECA/MINAE continue to work in collaboration with INTECO to further draft national standards (based on international standards) to be required for this technology.

The R-290 units have been used for almost two years without showing any problems. The intensive tests comparing units of different conventional technologies to eco-efficient ones, showed clear differences in energy consumption. Historical data from energy monitoring supports this trend and shows that eco-efficient units consume at least 40% less electrical energy on average when compared to units previously installed in the headquarters of the MOPT and Hotel Ambassador. Energy savings, cost savings and CO_2eq emissions mitigation are attaned. The difference in electricity demand according to the use given to the units was evident.

Converting energy savings into economic savings involves an analysis of the operational costs, i.e., energy consumption. In the comparison of the Inverter technology with R-290 with conventional technologies (conventional window and split AC), results show that, within 10 years, the investment of an eco-efficient unit is recovered, whether it is 12,000 BTU/h or 18,000 BTU/h. When comparing conventional *Inverter* technology with eco-efficient AC units, investment is only recovered if annual theoretical use data is used (1,951 hours). However, there are savings in the estimated annual use (800 hours), which favour replacing conventional technology with eco-efficient units. Also considering the theoretical installation and maintenance costs, it can be concluded that there is an internal rate of return (IRR) of 38.19% for 12,000 BTU/h units and 44.61% for 18,000 BTU/h units when comparing with the average *Inverter* technology units sold in 2019 in Costa Rica. There is a strong argument for replacing an old AC with an eco-efficient unit.

The total emissions of an eco-efficient unit are estimated at 1.5 tons CO_2eq, which results in a saving of 2.2 tons CO_2eq compared to commercial alternatives with HFCs. The low energy consumption is an opportunity to reduce indirect emissions. As Costa Rica has a high electricity generation from renewable sources, the approach to mitigate direct emissions has greater potential. In this regard, eco-efficient units are clearly the best alternative, since natural refrigerants such as R-290 have a GWP of only 3 kg CO_2eq./kg, as opposed to conventional refrigerants such as R-22 and R-410 which have GWPs of 1760 CO_2eq./kg, and 1923 CO_2eq./kg, respectively. An introduction of highly energy-efficient units can represent a saving of more than 0.3 megatons of CO_2eq annually by 2050 within the unitary AC sector.

There are many possibilities to upscale this technology in Costa Rica and in the Central American region. National entities such as the MOPT as well as international projects like GCF show interest in supporting such as the MOPT, as well as international projects, like the GCF, in supporting initiatives that promote the use of eco-efficient AC units. Historically predominant in China and India, split AC units with R-290 are currently entering the European markets. This technology is an opportunity to reduce the environmental impact of the RAC sector and is already being incorporated in other latitudes. Initiatives like this project materialise the beginning of these implementations in Costa Rica and the region.

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ANNEXES

Annex 1. Distribution of imported units.

	Program	12,000 BTU	18,000 BTU	TOTAL
Demonstration Project				
MOPT	4E	8	12	20
MOPT	4E	8	12	20
Ambassador	C4	13	5	18
MINAE (DCC, DIGECA, Main Building)	4E	0	1	1
FIFCO	4E	0	1	1
GIZ MyTransport	C4	0	1	3
Beirute	C4	1	1	2
Trainings				
INA	C4	0	8[80]	8
Samuel Foundation	C4	0	6	6
MEP (Calle Blancos)	4E	0	4	4
CEDES Don Bosco	C4	0	4	4
Replacement units	C4/4E	4	5	9
Total	C4/4E	36	64	100

Annex 2. General specifications of Godrej units.

General Specifications[81]		
Model name	GSC 12 GIG 5 DGOG	GIC 18 LAH 5 GWQG
Function	Cooling	Cooling
Nominal voltage	230	230
Operating voltage range	140-280	187-265
Total cooling capacity (W)	3,440	5,300
Cooling capacity at 50% (W)	1,720	2,650
Nominal input (W)	830	1,380
Nominal input at 50% (W)	310	448
Rated current (A)	3.9	6.7
Air flow (m3/h) (Turbo/High/Medium/Low)	630/580/510/470	1,400/1,100/900/800
SEER (BTU/Wh)	20.86	20.86
Product code	5NKYGG	40101701SD00653

80 This equipment was only loaned out for training purposes and has not been formally handed over to the INA.
81 Godrej & Boyce (2019): Service Manual for Godrej Air Conditioning Model SGC 12 GIG 5 DGOG & GIC 18 LAH 5 GWQG.

Annex 3. Specifications of compressors of Godrej units.

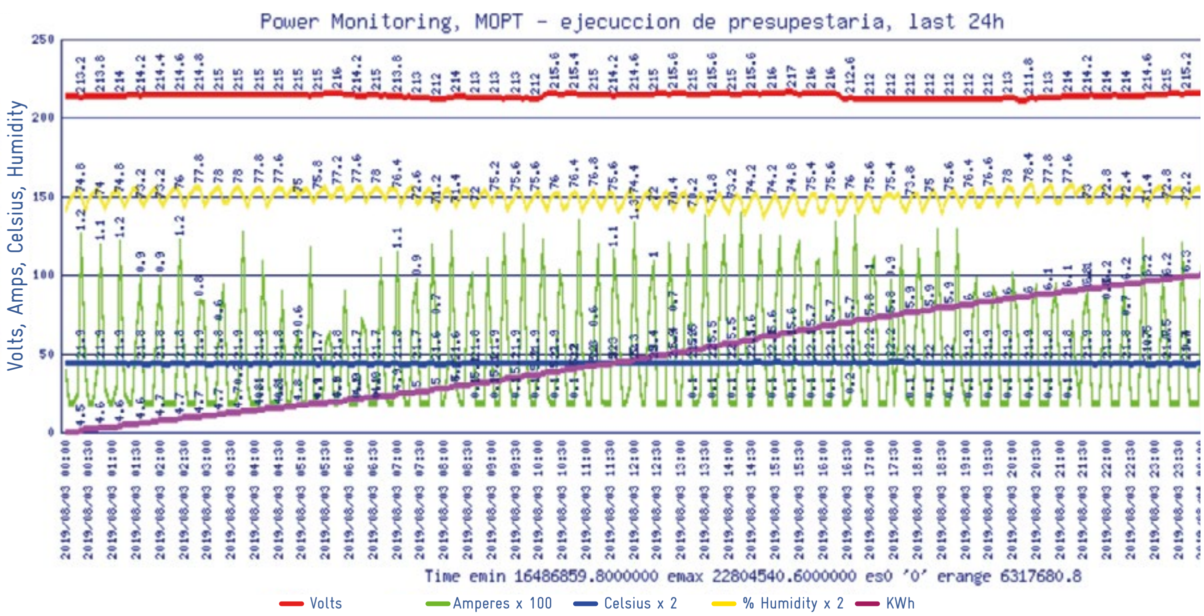
Compresors[82] [83]	GSC 12 GIG 5 DGOG	GIC 18 LAH 5 GWQG
Compressor model number	GMCC (DSM165D19UDT)	GMCC (DTN210D32UFZ)
Compressor type	Rotary	Rotary
Rated current (A)	5.1	6.2
Starting current (A)	13	NA
Total capacity (W)	2,885	3,680
Power input (W)	725	895
Overload protector	Internal	Internal PLO
Operating temperature range (°C)	16-31°C	16-50°C
Housing blanket provided	Yes	Yes

Annex 4. Safety standards to be implemented in Costa Rica.

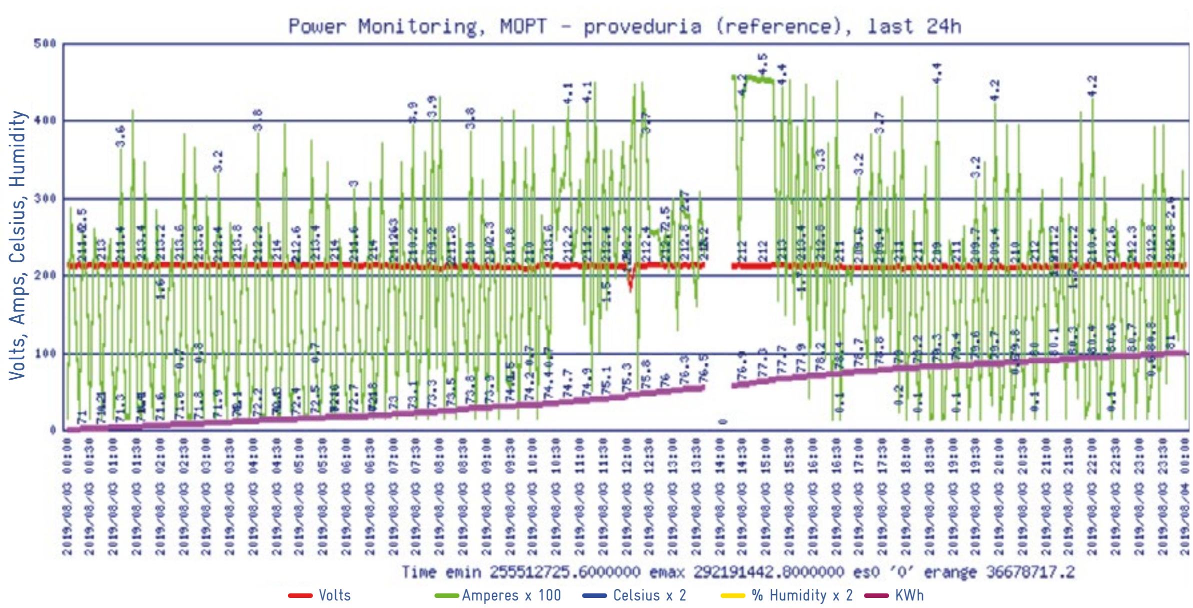
Safety standards under development, Costa Rica
National Technical Standard based on ISO 22712: *Cooling systems and water pumps warmth and competence of the staff*
National Technical Standard based on IEC 60335-2-40: *Safety for household electrical equipment, including air conditioners*
National Technical Standard based on ISO 13585: 2012: *Qualification test of welders and brazing operators*
National Technical Standard Legal obligation for all interested parties, with the requirement that only technicians trained within the framework of the MNC can carry out installation and maintenance work on the equipment.

82 Ibid.
83 GMCC, 2016: Hermetic DC Inverter Compressor Specification.

Annex 5. Energy monitoring, 12,000 BTU/h eco-efficient AC unit, GIZ 1.[84]

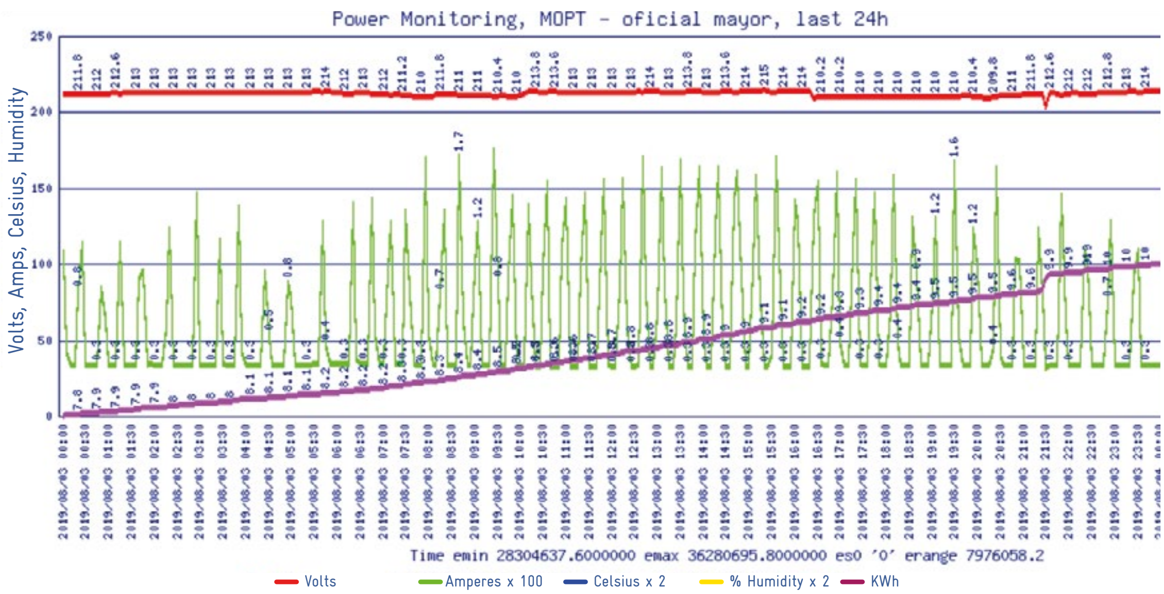


Annex 6. Energy monitoring, reference AC unit of 12,000 BTU/h, REF 1.[85]

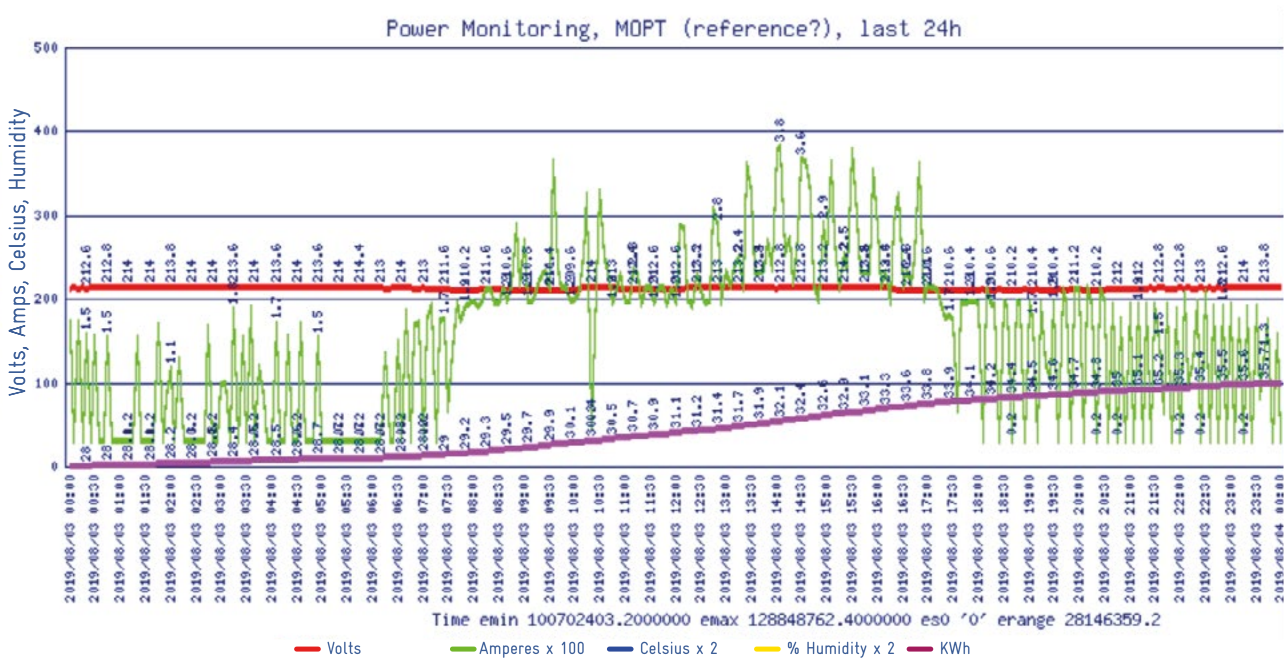


84 Go Goal, 2019: Energy Monitoring; Own calculations and design.
85 Ibid.

Annex 7. Energy monitoring, 18,000 BTU/h eco-efficient AC unit, GIZ 2.[86]



Annex 8. Energy monitoring, reference AC unit of 24,000 BTU/h, REF 2.[87]



86 Ibid.
87 Ibid.

Anexo 9. Historical data on energy monitoring, MOPT.[88]

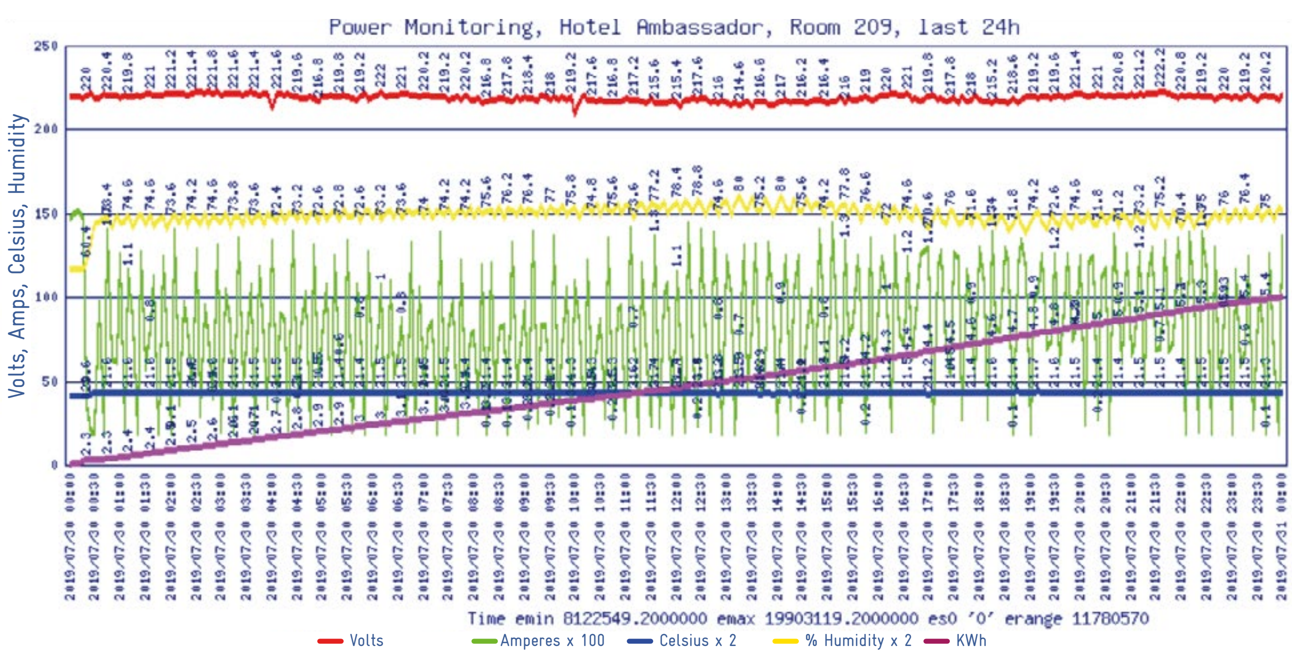
No.	Location	Unit	Classification	BTU/h	Days	Average current (A)	Total electricity consumption (kWh)	Daily electricity consumption (kWh)
1	MOPT	Computer assets	GIZ	18,000	129	0.75	410.60	3.18
2	MOPT	Transport Dispatch	GIZ	18,000	112	1.12	584.10	5.22
3	MOPT	Budget execution	GIZ	12,000	110	0.21	98.80	0.90
4	MOPT	Human Resources Computing	GIZ	18,000	109	0.19	56.50	0.52
5	MOPT	Contract work	GIZ	18,000	54	0.39	96.60	1.79
6	MOPT	Works by annexed contract	GIZ	12,000	24	0.19	19.00	0.79
7	MOPT	Senior Officer	GIZ	18,000	14	0.19	10.50	0.75
8	MOPT	Senior Officer	Reference Inverter	18,000	13	0.02	36.70	2.82
9	MOPT	Corporate Planning 1	GIZ	18,000	124	0.43	225.20	1.82
10	MOPT	Corporate Planning 2	GIZ	18,000	120	0.53	297.60	2.48
11	MOPT	Supplier's office	Referencia	12,000	57	0.42	236.40	4.15
12	MOPT	Programming and Control 1	GIZ	12,000	60	0.26	62.60	1.04
13	MOPT	Programming and Control 2	GIZ	12,000	59	0.33	77.70	1.32
14	MOPT	Reference	Reference Inverter	24,000	67	0.56	182.90	2.73
15	MOPT	Buildings room	GIZ	18,000	2	0.17	1.20	0.60
16	MOPT	Minister sessions	GIZ	18,000	59	0.31	78.90	1.34
17	MOPT	Vice-Minister Session	GIZ	12,000	39	0.17	25.40	0.65
Average					**67.76**	**0.37**	**147.10**	**1.89**

88 Ibid.

Annex 10. Theoretical savings according to efficiency, MOPT.[89]

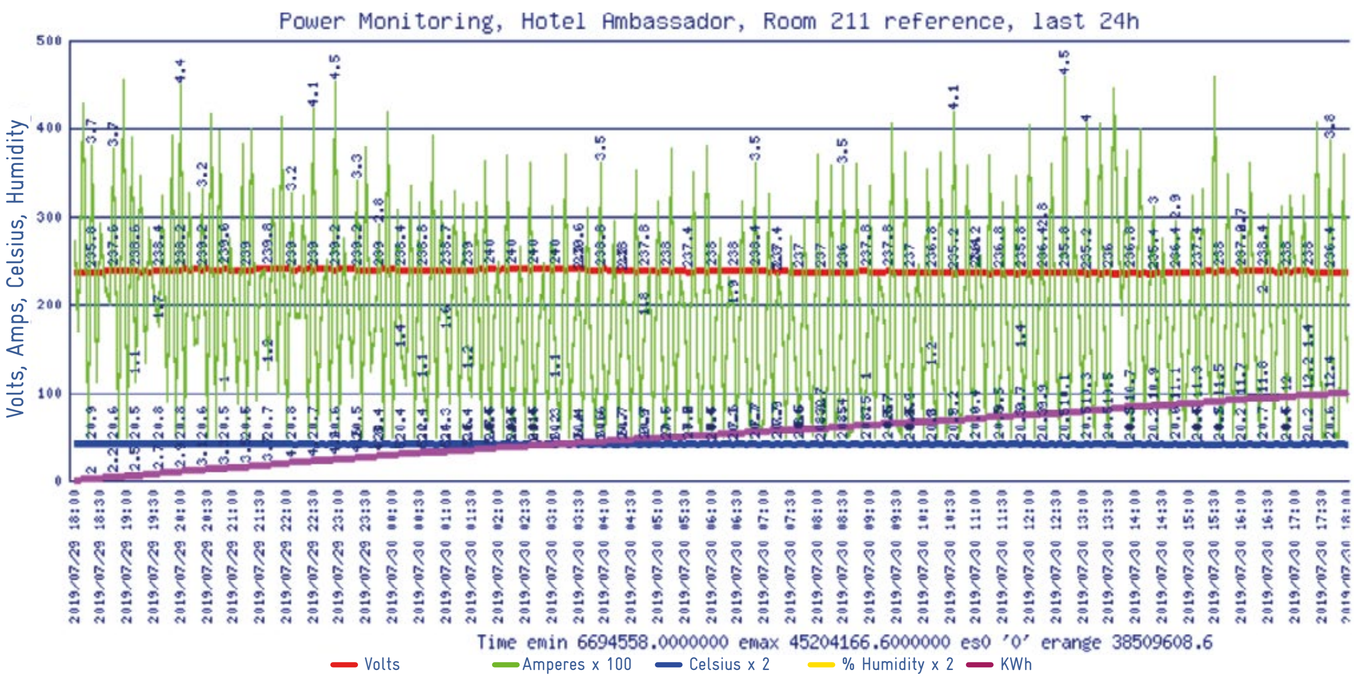
	12,000 BTU/h		18,000 BTU/h	
	Conventional	Ecoeficiente *Inverter*	*Inverter*[90]	Ecoeficiente *Inverter*
Typical use (rate)	Residential and commercial		Residential and commercial	
Cooling capacity (kW)	3.5	3.5	3.5	3.5
SEER	3.60	6.11	4.23	6.11
Load Factor (CDM)	0.75	1.0	1.0	1.0
Annual electricity consumption (kWh)	1,422.46	1,122.40	2,430.65	1,683.60
Annual electricity bill (¢)	181,088.82	143,190.14	310,089.76	214,785.22
Annual electricity bill ($)	312.22	246.88	534.64	370.32
Energy saving of eco-efficient unit (%)	**-21.06%**		**-30.77%**	

Annex 11. Energy monitoring, 12,000 BTU/h eco-efficient AC unit, GIZ 3.[91]



89 Own calculations and design.
90 Comparison with 24,000 BTU/h units.
91 Go Goal, 2019: Energy Monitoring; Own calculations and design.

Annex 12. Energy monitoring, 13,500 BTU/h reference AC unit, REF 3.[92]



92 Ibid.

Annex 13. Historical data on energy monitoring, Hotel Ambassador.[93]

No.	Location	Unit	Classification	BTU/h	Days	Average current (A)	Total electricity consumption (kWh)	Daily electricity consumption (kWh)
1	Ambassador	201	GIZ	12,000	57	0.34	92.50	1.62
2	Ambassador	203	GIZ	12,000	42	0.33	59.30	1.41
3	Ambassador	204	Reference	13,500	10	0.71	39.20	3.92
4	Ambassador	205	Reference	13,500	48	0.46	12.40	2.57
5	Ambassador	209	GIZ	12,000	70	0.28	75.00	1.07
6	Ambassador	211	Reference	13,500	10	0.46	26.20	2.62
7	Ambassador	212	GIZ	12,000	35	0.24	34.80	0.99
8	Ambassador	213	GIZ	12,000	62	0.34	79.90	1.29
9	Ambassador	302	GIZ	12,000	10	0.19	6.00	0.60
10	Ambassador	303	GIZ	12,000	28	0.34	35,.80	1.28
11	Ambassador	304	GIZ	12,000	11	0.28	11.20	1.02
12	Ambassador	310	GIZ	12,000	111	0.25	105.80	0.95
13	Ambassador	312	GIZ	12,000	88	0.33	117.00	1.33
14	Ambassador	313	GIZ	12,000	73	0.28	73.20	1.00
15	Ambassador	314	GIZ	12,000	10	0.17	6.10	0.61
16	Ambassador	315	GIZ	12,000	14	0.28	15.90	1.14
17	Ambassador	405	GIZ	12,000	7	0.30	7.30	1.04
18	Ambassador	Events room	GIZ	18,000	18	0.58	54.90	3.05
18	Ambassador	Events room 2	GIZ	18,000	18	0.48	37.70	2.09
Average					**38**	**0.35**	**52.69**	**1.56**

Annex 14. Theoretical savings according to efficiency, Hotel Ambassador.[94]

	12,000 BTU/h	
	Conventional	Ecoeficiente *Inverter*
Typical use (rate)	Residential and commercial	
Cooling capacity (kW)	4.0	3.5
SEER	3.12	6.11
Load Factor (CDM)	0.75	1.0
Annual electricity consumption (kWh)	1,869.29	1,122.40
Annual electricity bill (¢)	238,474.16	143,190.14
Annual electricity bill ($)	411.17	246.88
Energy saving of eco-efficient unit (%)	**-39.47%**	

93 Go Goal, 2019: Energy Monitoring; Own calculations and design.
94 Own calculations and design.

Annex 15. Summary of historical energy monitoring conducted in other locations.[95]

Unit	Number of days	Average current (A)	Total electricity consump-tion (kWh)	Daily electricity consump-tion (kWh)	Total Hours (h)	Daily Power-on Time[96] (%)	Hours Daily ignition (h)
DCC	10	0.14	3.40	0.34	23.00	9.6%	2.30
DIGECA	69	0.16	45.40	0.66	203.50	12.3%	2.95
MINAE	8	0.38	7.70	0.96	21.50	11.2%	2.69
MyTransport 1	17	0.29	17.40	1.02	57.00	14.0%	3.35
MyTransport 2	14	0.38	21.80	1.56	49.00	14.6%	3.50

Annex 16. Historical data on energy monitoring by location.[97]

Location	Tipo	BTU/h	Units	Average days of use	Average current (A)	Average total energy consump-tion (kWh)	Average daily energy consump-tion (kWh)
Ambassador	GIZ	12,000	14	44.14	0.28	51.41	1.10
Ambassador	REF	13,500	3	22.67	0.54	62.93	3.04
Ambassador	GIZ	18,000	2	18.00	0.53	46.30	2.57
MOPT	GIZ	12,000	3	62.67	0.26	71.47	1.16
MOPT	GIZ	18,000	11	75.18	0.40	166.39	1.72
MOPT	REF	12,000	1	57.00	0.42	236.40	4.15
MOPT	REF	24,000	2	40.00	0.29	109.80	2.78
ICE	GIZ	12,000	1	21.00	0.31	14.60	0.70
ICE	GIZ	18,000	1	22.00	0.65	44.10	2.00
Other demonstrations	GIZ	18,000	5	23.60	0.27	19.14	0.91

95 Go Goal, 2019: Energy Monitoring; Own calculations and design.
96 Estimated value according to own definition of ignition. It is not recommended to use it for further calculations.
97 Go Goal, 2019: Energy Monitoring; Own calculations and design.

Annex 17. Comparison of *Inverter* technology with different refrigerants.[98]

BTU/h	12,000 BTU/h		18,000 BTU/h	
Coolant	Conventional (R-410A)	R-290	Conventional (R-410A)	R-290
Fee per type of use	Residential and commercial		Residential and commercial	
Hours of daily use	6	6	6	6
Annual hours of use	1,951	1,951	1,951	1,951
Cooling capacity (kW)	3.52	3.52	5.28	5.28
SEER	19.00	20.86	19.00	20.86
CDM Load Factor	1.0	1.0	1.0	1.0
Annual energy consumption (kWh)	1,231.53	1,122.40	1,847.29	1,683.60
Annual electricity bill (colones)	157,112.15	143,190.14	235.668,22	214.785,22
Annual electricity bill (dollars)	270.88	246.88	406.32	370.32
R-290 energy savings	**-8,86%**		**-8,86%**	

98 Own calculations and design.

Annex 18. Summary table of financial internal rate of return (IRR) calculation at 10 years, 12,000 BTU/h.[99]

Comparison Scenario 12,000 BTU/h Inverter										
Year	1	2	3	4	5	6	7	8	9	10
Cash flows in AC with R-410A Inverter ($)										
Cost of AC	-614.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation cost	-162.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02
Electric Billing	-299.38	-299.38	-299.38	-299.38	-299.38	-299.38	-299.38	-299.38	-299.38	-299.38
Net cash flow	-1,130.24	-353.41	-353.41	-353.41	-353.41	-353.41	-353.41	-353.41	-353.41	-353.41
Cash flow in AC with R-290 Inverter ($)										
Cost of AC	-706.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation cost	-162.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02
Electric Billing	-272.85	-272.85	-272.85	-272.85	-272.85	-272.85	-272.85	-272.85	-272.85	-272.85
Net cash flow	-1,195.93	-326.88	-326.88	-326.88	-326.88	-326.88	-326.88	-326.88	-326.88	-326.88
Difference in cash flows (R-290 less conventional)	-65.69	26.53	26.53	26.53	26.53	26.53	26.53	26.53	26.53	26.53
TIR	38%									

99 Own calculations and design.

Annex 19. Summary table of calculation of financial internal rate of return (IRR) at 10 years, 18,000 BTU/h.[100]

Comparison Scenario 18,000 BTU/h Inverter										
Year	1	2	3	4	5	6	7	8	9	10
Cash flows in AC with R-410A Inverter ($)										
Cost of AC	-838.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation cost	-162.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02
Electric Billing	-449.07	-449.07	-449.07	-449.07	-449.07	-449.07	-449.07	-449.07	-449.07	-449.07
Net cash flow	-1,503.58	-503.10	-503.10	-503.10	-503.10	-503.10	-503.10	-503.10	-503.10	-503.10
Cash flow in AC with R-290 Inverter ($)										
Cost of AC	-964.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation cost	-162.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02	-54.02
Electric Billing	-409.28	-409.28	-409.28	-409.28	-409.28	-409.28	-409.28	-409.28	-409.28	-409.28
Net cash flow	-1,589.55	-463.30	-463.30	-463.30	-463.30	-463.30	-463.30	-463.30	-463.30	-463.30
Difference in cash flows (R-290 less conventional)	-85.97	39.79	39.79	39.79	39.79	39.79	39.79	39.79	39.79	39.79
TIR	**17.89%**									

100 Own calculations and design..

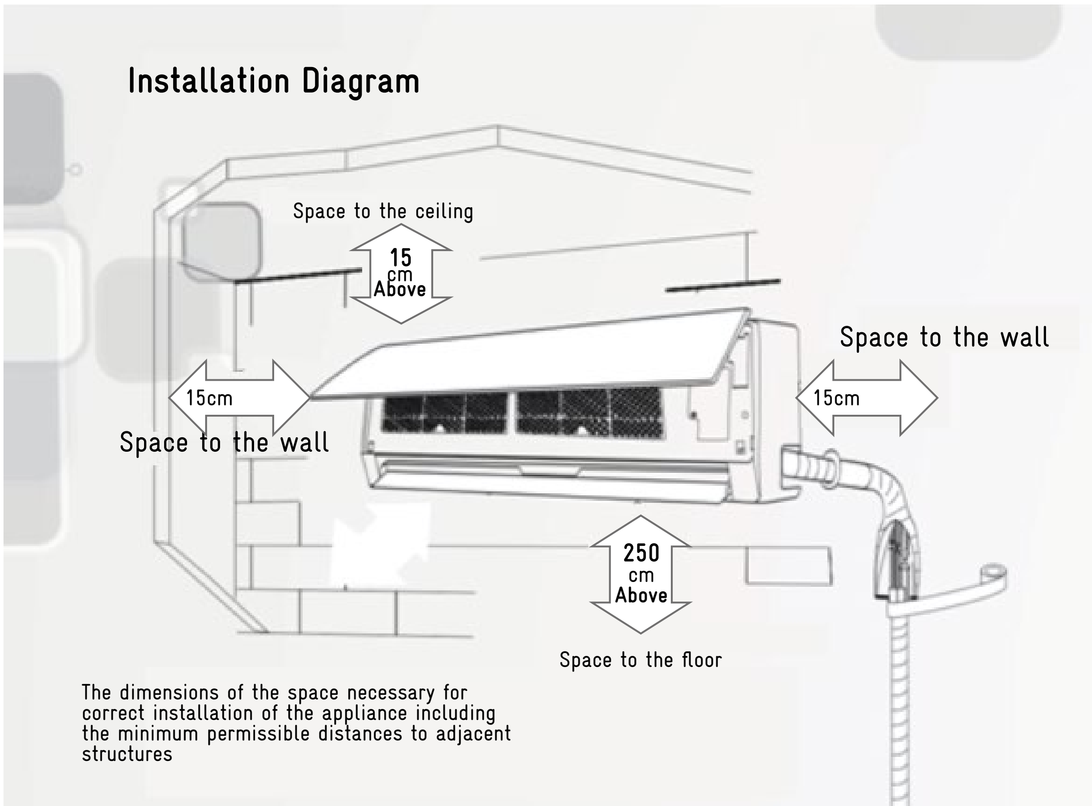
Annex 20. GIZ Proklima Refrigerant Management Training Curriculum R-290 and R-600a.

Split type A/C training with R-290 and domestic refrigeration with R600a - Training schedule (Modules) - Safe use of hydrocarbon refrigerants

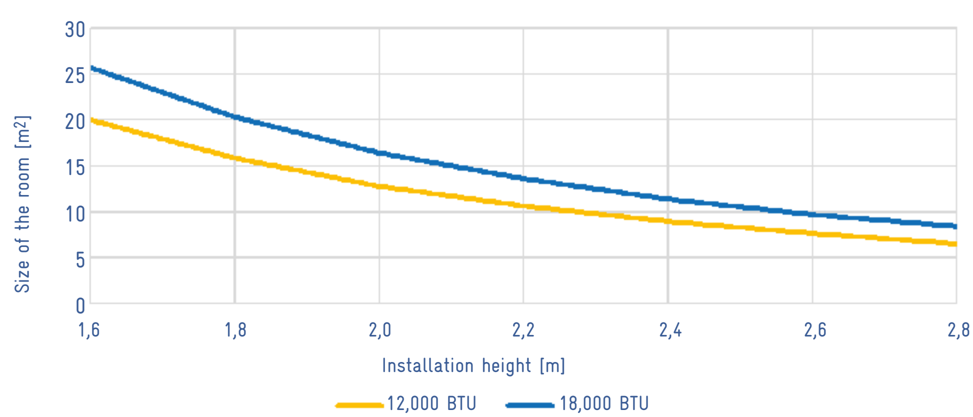
	Day 1 (Monday) Welding training	Day 2 (Tuesday) Brazing Training / HC Training	Day 3 (Wednesday) HC Training	Day 4 (Thursday) HC Training	Day 5 (Friday) HC Training
08:00 a.m. to 12:00 p.m.	**A0 Official opening and introduction (45 min.)** -Presentation of the participants -Expectations, objectives and seminar program -Rules **Brazing (60') Theory** - Importance of Brazing in the RACHP Industry - Welding theory - Brazing and Tooling Safety - Importance of brazing for use with hydrocarbons - Welding operation - Certification of welders' competence - brazing sample - Use of press connectors - Filter drier installation (if applicable) - Sealing of process pipe maintenance connections (in case of pinch-off) **BP1 Practical exercise** - Construction of the brazing cylinder (135') - Informative meeting with the participants: Job description, tool list, risk assessment - Workplace Preparation - Execution of the work according to the needs - Prepare and practice up to 5 test pieces for brazing	**BP1 continued (240')** - See Day 1	**Repetition** (what did we learn yesterday?) **A3 Cylinders and cylinder handling (30')** - Cylinder handling - Cylinder storage - Cylinder transport **A4 Regulations, safety standards and guidelines (165')** - National legislation, product safety marks - International RACHP standards - Intrinsically safe equipment - Explosive Atmospheres - Load size limitations for flammable refrigerants - How do the rules affect me? - Calculation exercises and examples **A5 Procedures, tools and equipment for the use of flammable refrigerants (45')** - Basic approach to working with flammable refrigerants - The combustion triangle - The work environment - Temporary Flammable Zones	**Repetition** (what did we learn yesterday?) **A10 Refrigerant Recovery (50')** - Release of natural refrigerants into the atmosphere - Hydrocarbon Coolant Ventilation - Burning HC flammable refrigerants - Flammable refrigerant recovery **A11 Leak test (40')** - Importance of Refrigerant Leak Detection Activities - Legal requirements and waterproofing standards - The most common leaks - Leak test methods (direct/indirect) **A12 Electrical Safety (30')** - The five rules of electrical safety -Mandatory electrical safety testing **AP1 Practical Exercise - Installation of the empty unit (120') or AP1.1 Installation of the pre-loaded unit (120')** - Preparation and risk assessment - Installation of indoor/outdoor unit, refrigerant transfer lines, insulation - Process electrical wiring and cable connections - Pressure testing and circuit washing - Preparation for start-up - Tools and instructions such as those given in the session summary	**Repetition** (what did we learn yesterday?) **AP3 Practical Exercise - Final Leak Check, Labeling, Reporting and Delivery of Refrigeration R-290 A/C & Ref- R600a (120')** - Preparation - Functional check, electrical safety check, final leakage check - Documentation and communication with clients - Delivery - Tools and instructions such as those given in the session summary **Final evaluation (120')** - Theoretical Evaluation Test - Recapitulation

Lunch break	12:00 p.m. – 1:00 p.m.	12:00 p.m. – 1:00 p.m.	12:00 p.m. – 1:00 p.m.	12:00 p.m. – 1:00 p.m.	12:00 p.m. – 1:00 p.m.
1:00 p.m. to 4.30 p.m. / 5:00 p.m.	**Continuation of brazing practices (210')** – Material for the test sample – Perform the necessary burns – Produce the test specimen according to the drawing provided – Brazing under inert gas protection (OFDN) – Running the pressure test and the leakage test – Process Pipe Sealing – Cleaning and marking of the sample Cleaning – Delivery of the checklist and test sample **Daily evaluation**	**A1 Introduction to Refrigeration and Natural Refrigerants (60')** – Refrigeration and air conditioning – Environmental aspects of refrigerants and environmentally friendly alternatives – Application of flammable refrigerants (different types of equipment and examples) **A2 Safety and risk precautions in the handling of refrigerants (90')** – Safety and health protection in the workplace –Why do accidents happen? How can they be avoided? (PPE) –Substances under pressure –Safety Marks –Fire Protection –First Aid **A3 Cylinders and cylinder handling (30')** – Compressed gas cylinders – Color coding and cylinder labeling – Cylinder assembly	**A5 Procedures, tools and equipment for the use of flammable refrigerants (45' incl. 30' demonstration)** – Tools and work equipment specifically for use with flammable refrigerants **A8 Sealed System Design (50' incl. 10' demonstration)** – Important components for the design of sealed systems – Purpose and function of the different refrigerant transfer tubes – Connecting options for refrigerant transfer tubes **A9 Installation, commissioning and maintenance of R-290 A/A (40')** – Preparation of the installation – Refrigerant transfer pipe routing and support – Pipe Insulation – Start up – Repair or modification of a system **ADR Repair of domestic refrigerator R600a (60')** – Overview of domestic refrigerators Basic refrigeration – The use of pressed joints – Provision of sealed systems – Operation of domestic refrigerators with HC – Problem solving – Maintenance and repair – Washing with OFDN (and HC) – Pressure testing with OFDN – Filter changes – Electrical safety and commissioning **Daily evaluation**	**AP2 Hands-on Exercise Start-up and Operation (180') or AP2.1 R-290 A/C Repair (180')** –Preparation and Risk Assessment – Recovery – Functional check, electrical safety check, final leakage check – Documentation and communication with clients – Tools and instructions such as those given in the session summary **Parallel working groups: AP Domestic Refrigerator R600a (180')** – Preparation and risk assessment – Problem solving – HC Refrigerant – Ventilation – Repair – Washing with OFDN (and HC) – Filter drier change – Pressure testing with OFDN – Start up – Sealing of the refrigerant circuit (pinching of the process vessel) avoiding schrader valves – Final leakage check – Functional check, electrical safety check – Documentation and communication with clients – Delivery – Tools and instructions such as those given in the session summary	**Closing (60')** – Photo – Written evaluation of the workshop – Certificates and farewell

Annex 21. Installation diagram of AC split type equipment with R-290 refrigerant.[101]



Annex 22. Installation height of AC equipment with R-290 according to the size of the room.



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