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A METHOD TO EVALUATE ENERGY PERFORMANCE OF BUILDINGS COOLED BY ROOM AIR CONDITIONERS

Franck LUCAS[a]*, Pascal ORTEGA[a], Mathieu DAVID[b], Frantz SINAMA[b], Boris BRANGEON[b] Fabien PICGIRARD[c]

Univerity of french Polynesia, Laboratory GEPASUD, Tahiti.
[b]*University of Reunion Island – Laboratory PIMENT, Reunion Island, France*
[c]*ADEME Reunion, Reunion Island, France*

Abstract

Because of their low cost, small air conditioning systems (AC) like split air conditioning systems are often installed without a proper study of building envelope performance. Furthermore, these systems are sometimes installed by tradesmen who neglect to comply with the appropriate rules and regulations. Finally, when routine maintenance is not rigorously carried out (as so often happens), the energetic performance of the system is compromised over time. This article presents a practical, global approach to diagnose the performance of existing small air-conditioning installations in buildings applied in Reunion Island. This tropical Island aspires to become electricity self-sufficient.. This approach relies on a numerical tool and dynamic simulations of buildings equipped with AC. The simulations, which take account of the building envelope, a description of the system as well as the practices of the users, are based on the kernel calculation EnergyPlus. They also take into account the climatic conditions and provide an estimate of the annual electricity consumption related to the cooling of the zone. This global analysis helps to qualify the entire system by assigning an energy label. In addition to the tool, a diagnostic procedure is proposed, helping an auditor defining guidance to improve the building envelope and to install and maintain the system.

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"Keywords: Energy label, building performance, small air conditioner, warm climates"

1. Introduction

Buildings account for over 42% of consumption of final energy [1] in France and between 20 and 40% in other developed countries. Perez Lombard [2] reports that the share of HVAC system for heating, ventilation and air conditioning has now become the largest energy end use in the residential and non-

1. * Corresponding author. Tel.: +689 87 334 301

E-mail address: franck.lucas@upf.pf.

residential sector. Wong [3] estimates that its represents one third of the total energy consumption for residential housings in Hong Kong. Improving the design of buildings and of the AC systems in order to reduce cooling loads is the subject of a great deal of research in southern hemisphere tropical climates. A large body of expertise has evolved, especially in respect to French overseas departments, like Reunion Island [4], [5]. As a result of this work, specific recommendations to design buildings adapted to the tropical climate have been established. The PERENE tool [6], was established in 2004 and modified in 2009. Its application was not mandatory. The first thermal regulation for overseas departments, called RTAADOM, was published in 2009 [7]. Reunion Island as many isolated areas, is faced with specific energy issues. Residential and small commercial buildings are almost exclusively equipped with small air conditioning units. Small room air conditioning units (RAC) are freely available for purchase in shops and in most cases, few regulations control their installation. In the European country attempts have been made to define global procedures to rate and label buildings and/or their components [8] [9] [10] [11] as well as in the US [12], [13]. Beside comprehensive energy assessment performance methodologies dedicated to large buildings like those developed by Richalet [14], Zmeureanu [15], Siaw Eang [16], there is a need for a specific methods, dedicated to small housing or offices equipped with room air conditioners. The challenge is to develop a method allowing the audit of small office buildings which are mostly equipped with split system. This paper presents a pragmatic and combined approach for the labeling and for the improving of existing buildings based on a noncommercial numerical tool. It was developed for tropical territories in the southern hemisphere where only space cooling is necessary in buildings. It is based on hourly dynamic simulations over a period of one year but with a specific simplified interface, that helps the auditor describing the installation and the building in a very short time. Although the time to complete the installation description is short, the results proposed are sufficiently comprehensive to guide the auditor to improve the installation. The specificity of this approach is that the duration of the audit is shortened in order to reduce its cost. The aim is to make the auditing cost consistent with the cost of the room air conditioner, which is very low. For the audits be undertaken on a significant scale and in a short time, it must remain simple in its implementation and involve the use of computer programs.

2. The simulation tool

2.1. Input and output

The main objective of the simulation program is to establish a rapid but global diagnostic of air conditioners and of the building envelope. The program also helps to determine the size of the system needed by considering the premise's thermal loads and evaluating the optimum cooling power required. This program is based on the EnergyPlus simulation code [17], which provides the simulation core. A graphical interface allows the rapid entry of input variables as well as the display of the generated output. Since the simulation program is pitched at auditing premises with a small air conditioning unit such as a split system type, the building studied is considered as a single thermal zone. The software architecture is as follows:

- A user interface for entering parameters to define the building and the system characteristics (Fig 1). To perform a fast audit, the building description must be simplified. Therefore, many input data are predefined in the software according to the most common construction methods used in Reunion Island. This interface allows the description of all characteristics of the building envelop (roof, walls, windows) including the solar protection for walls and windows, the internal sensible and latent loads (lighting, equipment, peoples…), the ventilation devices, the infiltration of air inside the building, and of course all the characteristics related to the air conditioning system (power, efficiency ratio, set point temperature, implementation, maintenance procedure…).

- An interface for viewing the simulation results (Fig 1). The output values of the software are of three types: Energy labels for classifying from A to F the main features of the facility, the rating for each of the walls and windows, the level of infiltration and the global label to qualify the overall building envelope. Some numerical output values are proposed to the auditor, e.g. maximum inside temperatures, optimum cooling capacities, EER and solar factor calculated by EnergyPlus, average power consumption, etc. It also possible editing hour by hour evolutions of the figures characterizing inside and outside conditions of the room, provided in a ".CSV" file.
- A core calculation which performs a first "design run", to determine the required cooling capacity on a specific weather data file characteristic of a hot summer day. The second simulation run is performed on an annual weather data file in order to evaluate the overall performance of the installation with its electricity consumption, its Energy Efficiency Ratio (EER), its Seasonal Energy Efficiency Ratio (SEER) using the reference to the Eurovent certification of air conditioning systems [18], etc.

While the program is designed to evaluate the behaviour of an air-conditioned room, it also allows the simulation of buildings operating without air conditioning system.

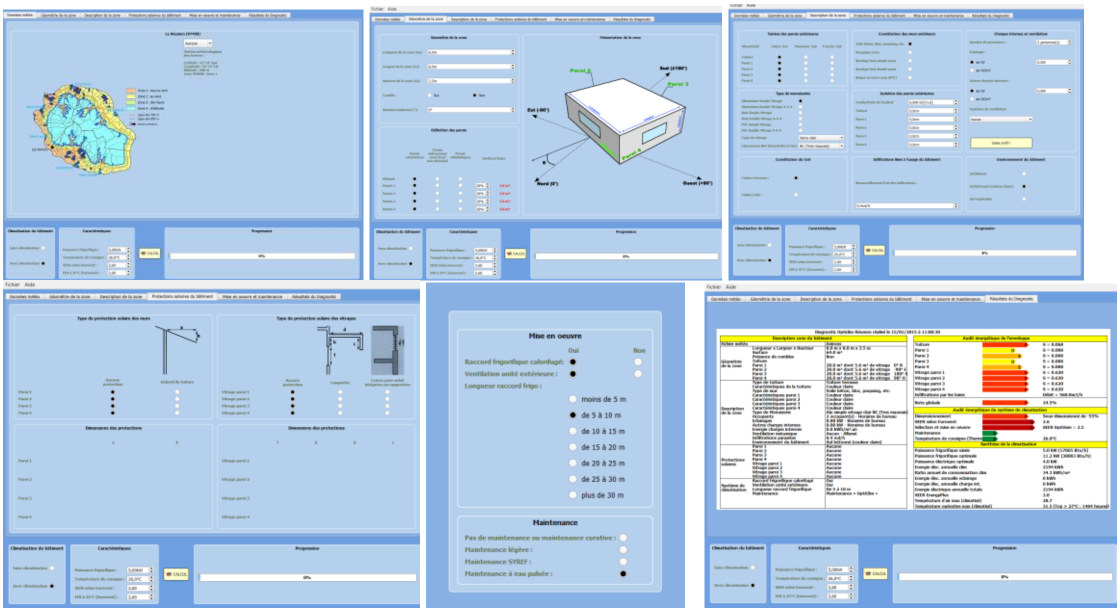


Fig. 1. Main tabs of the user interface. (From the top left to bottom right: site location and climate tab, building geometry description tab, building components description tab, solar protections description tab, HVAC system description tab, output tab)

2.2. Envelop labelling

The determination of target values for the qualification of the envelope relies on the definition of the solar factor for windows and walls. This indicator is relevant in tropical climates because it takes into account both the long wave and short wave thermal fluxes. Solar factor can be estimate in steady state with the formula for walls or windows provided in the Perene tool [19]. It can be also evaluated from dynamic calculation of thermal fluxes provided by Energyplus. Thus, the solar factors are obtained when dividing transmitted fluxes through a wall by the incident radiation on this wall. The target values to assign a label and to define the quality of the walls and the windows expressed by the solar factor depend on the orientation of the wall. The targets to allocate the label of a wall are set out in the table 1 and defined according to the values of solar factor reported in the Perene tool [19] and the thermal regulation for French overseas territories RTAAdom [7].

Table 1: Solar factor F for envelop components

Roof	wall		window				Label
	North, west, east	South	North	West	East	South	
F< 0.012	F< 0.045	F<0.06	F< 0.225	F< 0.15	F< 0.15	F< 0.30	A
0.012<F<0.015	0.045<F< 0.06	0.06<F<0.08	0.225 < F< 0.3	0.15 <F< 0.2	0.15 <F< 0.2	0.30< F< 0.4	B
0.015<F< 0.02	0.06<F< 0.075	0.08< F<0.1	0.3 < F< 0.375	0.2 <F< 0.25	0.2 <F< 0.25	0.4 <F< 0.5	C
0.02<F<0.03	0.075<F< 0.09	0.1< F<0.12	0.375<F< 0.45	0.25<F< 0.3	0.25<F< 0.3	0.5< F< 0.6	D
0.03 < F< 0.04	0.09 < F< 0.12	0.1< F<0.16	0.45<F< 0.6	0.3< F< 0.4	0.3< F< 0.4	0.6< F< 0.8	E
0.04 < F	0.12< F	0.16< F	0.6< F	0.4 < F	0.4 < F	0.8< F	F

Table 3, given below, provides the classification of windows related to air infiltration and air infiltration flow rate in m3/h/m² of opening according to COSTIC recommendations for island area [20]. The computer program assigns a label to each component of the building envelope. It also determines an overall mark for the whole envelope by comparing the building in question to a reference building. This reference building has the same geometry as the actual one but is given a label A for all its walls and windows. For example, the solar factor for the roof of the reference building is 0.012. It is 0.045 for the north, west and east walls and 0.06 for the south wall. The program calculates the energy transmitted by the walls Qref, for the reference building following the equation (1) and the energy Q transferred through the walls of the actual building. The label is assigned by reference to table 3.

$$Q_{ref} = 0.012 \cdot S_{roof} + 0.045 \cdot (S_{wall\,N} + S_{wallW} + S_{wall\,E}) + 0.06 \cdot S_{wall\,S} + \\ 0.225 \cdot S_{windowN} + 0.15 \cdot (S_{window\,W} + S_{windowE}) + 0.3 \cdot S_{windowS} \quad (1)$$

Beside the label, a global grade expressed as a percentage is provided to the auditor to evaluate precisely the global quality of the envelope:

$$\text{Global envelope grade} = (Q - Q_{ref}) / Q_{ref} \quad (2)$$

2.3. Air conditioning split system labeling

Several labels are needed to properly describe a split system:

- A “system label” to qualify the choice of a particular system among the models on the market.
- A “sizing label” to indicate whether the installed cooling capacity is matched to zone requirements.
- A “maintenance label" to indicate the quality and frequency of scheduled maintenance.

These labels are meant to indicate the performance of the RAC in the actual operating conditions, taking into account all the factors that could degrade the performance. Usually, this evaluation operates in two steps. The first is to determine the value of the EER that reflects the instantaneous system efficiency at full load. The EER value for the system can be determined using the manufacturer data or the Eurovent certification [18]. To establish the label, the auditor must use the value established by Eurovent called $EER_{eurovent}$ and not the value from the manufacturer. The second step is to consider the partial-load operation by multiplying the EER by the Part Load Factor (PLF) [21]. The PLF is deducted from the Part Load Ratio (PLR) defined as the ratio of the building thermal load to the HVAC system full cooling capacity [22]. The Seasonal Energy Efficiency Ratio (SEER) was introduced to reflect the influence of changes in external conditions on the behaviour of different types of HVAC systems. For European weather conditions, Adnot [23] established a specific factor: the European Seasonal Energy Efficiency Ratio (ESEER). However, an air conditioning system operating in a real building sees its performance affected by other factors. The diagnostic program introduces a coefficient K1 qualifying maintenance and influencing the seasonal performances. The value of the EER_{sys} used to determine the “system label" is set out in Table 3 below, using the coefficient K2 which takes into account the implementation (equation (3)). Tables 2 and 3 give the values for K2 and K1 respectively. The system classification is based the EER_{sys} value and refers to the Eurovent classification. A difference of 0.2 between the class limits of the tool and Eurovent is introduced to promote more efficient systems. The target values for the auditing tool and from the Eurovent certification appear in the table 3. The model of the air conditioning system evaluates the performance degradation of the split system, depending on sizing and operating conditions. The diagnostic program adjusts this estimation by computing a particular value of the SEER designated by $SEER_{calculated}$, to account for the maintenance and installation. It also determines the cooling capacity required when the thermal zone is maintained at the specified set-point temperature during the use of air conditioning. This cooling capacity required, calculated by Energylplus, correspond to the maximal value of the building cooling load observed during the “design run”. The software infers the required electrical power relative to the required cooling capacity. Electrical power is calculated by dividing the required cooling capacity by the value of the energy efficiency ratio of the system when the electrical power is required. This specific value of the EER is estimate by the $SEER_{calculated}$. The calculation of the electrical power introduces also the coefficients K1 and K2, i.e.

$$EER_{sys} = K_2 \cdot EER_{Eurovent} \qquad \dot{Q}_{elec,req} = \frac{\dot{Q}_{cool,req}}{K_1 \cdot K_2 \cdot SEER_{calculated}} \qquad Q_{elec,annual} = \frac{Q_{cool,annual}}{K_1 \cdot K_2 \cdot SEER_{calculated}} \qquad (3)\ (4)\ (5)$$

The annual electrical energy is calculated from the annual cooling energy delivered in the thermal zone and the $SEER_{calculated}$ value determined by EnergyPlus using the formula (5). The size or capacity of the system is evaluated by comparing the actual cooling capacity installed with the required cooling capacity assessed by the software. A difference lower than 30% between these two values provides access to the label A. The classification proposed in table 3 has been elaborated empirically for this project considering the available power range of RAC on the market. Beside the label, a grade, expressed as a percentage, is provided to the auditor to evaluate precisely the AC system sizing. The sizing grade is:

$$sizing\ grade = (Q_{cool,installed} - Q_{cool,req}) / Q_{cool,req} \qquad (6)$$

The quality of the maintenance contract affects the “maintenance label" and results in performance degradation for the RAC through the coefficient K1. Few data are available to assess the impact of fouling on energy performance of air conditioners. Therefore specific experiments were carried out for this study. The Table 3, giving the values for K1, is based on these experiments carried out in Reunion Island on different sizes, models, operating conditions and maintenance procedures during 18 month. This work will be published soon. This study tested the following maintenance procedure:

- Type 1 : Specific Opticlim contract (with heat exchanger water jet washing)
- Type 2 : Comprehensive annual maintenance and regular cleaning of filters
- Type 3 : "Light" maintenance : annual recharge of refrigerant, no control, no filter cleaning
- Type 4 : No maintenance

The quality of the HVAC system installation, including the length of refrigerant line between the outdoor unit and indoor unit, the insulation of the refrigerant line and the ventilation of the outdoor unit, also has a significant influence. The coefficient K2 which account for these parameters is affected as seen in Table 2.

Table 2: Figures for K2

Refrigerant line insulation	With		Without (or degraded)	
Good ventilation of outdoor unit	yes	no	yes	no
Refrigerant line lenght	Coefficient K2 values			
< 5 m	1	0.97	0.93	0.91
5 to 10 m	0.97	0.96	0.86	0.83
10 to 15 m	0.96	0.95	0.79	0.74
15 to 20 m	0.95	0.93	0.73	0.65
20 to 25 m	0.93	0.91	0.61	0.54
25 to 30 m	0.92	0.9	0.49	0.43
> 30 m	0.80	0.7	0.45	0.40

Table 3: Classification and label for windows, infiltration, envelop, systems and maintenance

Windows and infiltration			envelop	System label		Maintenance label		System sizing	Label
Air tightness	Flow rates	Joinery types	Value of Q	References	Eurovent label	Type	K1	References	
A3	1.2	Classified windows	Q< 1.3 Qref	3.4<EER sys	3.2<EER sys	1	1	$\dot{Q}_{cool,installed} < 1.3\dot{Q}_{cool,req}$	A
A2	3	Classified windows	1.3Qref< Q<1.7Qref	3.2<EER sys< 3.4	3.0<EER sys<3.2	2	0.92	$1.3\dot{Q}_{cool,req} < \dot{Q}_{cool,installed} < 1.5\dot{Q}_{cool,req}$	B
A1	7	Classified windows	1.7 Qref < Q < 2.3 Qref	3.0<EER sys<3.2	2.8<EER sys<3.0	3	0.85	$1.5\dot{Q}_{cool,req} < \dot{Q}_{cool,installed} < 1.7\dot{Q}_{cool,req}$	C
A0	15	Gliding windows	2.3Qref< Q<3Qref	2.8<EER sys<3.0	2.6<EER sys<2.8	4	0.75	$1.7\dot{Q}_{cool,req} < \dot{Q}_{cool,installed} < 1.9 \times \dot{Q}_{cool,req}$	D
Not defined	25	Louvers	3Qref<Q <4Qref	2.6<EER sys<2.8	2.4<EER sys<2.6			$\dot{Q}_{cool,installed} > 1.9\dot{Q}_{cool,req}$	E
			4Qref>Q	2.4<EER sys<2.6	2.2<EER sys<2.4				F
				EERsys <2.4	EERsys< 2.2				G

3. Methodology of implementation

The energy audits of existing premises equipped with split system air conditioning supposes a Public Information Program This program includes dissemination actions to promote this approach to the public, to owners and to potential energy auditors, as well as training programs for the energy auditors. A French public body supports financial costs of this approach in order to promote the demand side management on the territory. First of all, the public body funded the development of the tool and the dissemination program including the training sessions. It also proposes financial support for the audit phase. The audit of one building is charged 2000 euros by the auditor. The support provided by the public body is fifty percent of the cost for private building owners and seventy percent for public building owners. This cost is consistent with the study reported by Rhodes of a large energy audit performed on homes in Texas [24].

4. Conclusion

The process of diagnosing small air conditioning installations as presented in this paper proposes a performance assessment of building equipped with small room air conditioners. This approach is based on a dynamic simulation tool, which provides figures and label guiding the auditor to reduce energy consumption of a building. The thermal description of a zone is simplified thanks a dedicated interface and the time for the simulation over a one-year period is less than forty seconds. The figures help the auditor quantifying the performances improvement between the actual and the modified building. The labels are intended to provide to the owner, simple information on the energy quality of his building. The implementation of the tool on real case buildings have shown that the prediction of the energy consumption provided by the audit is in good agreement with the experimental measurements and with the electricity utility bills. Audits of existing building highlight that some improvement may be implemented, leading to an average reduction of 20% of the energy consumption.

Nomenclature

α : absorptivity of material [-]

cm : coefficient of reduction to account of solar protection [-]

EER : energy efficiency ratio [-]

ESEER : European seasonal energy efficiency ratio [-]

F : Solar factor [-]

K1 : coefficient taking into account the maintenance of the air conditioning system [-]

K2 : coefficient taking into account the implementation of the air conditioning system [-]

PLF: Part load factor [-]

PLR : Part load ratio [-]

: energy [J]

: power [W]

Rth : thermal resistance off wall [m^2.K.W-1]

SEER : seasonal energy efficiency ratio [-]

S : surface [m^2]

Subscript:

Cool : cooling

E : east

Elec : electrical

N : north

Req : required

Sys : system

S: south

W: west

References

[1] Plan climat 2011. Politiques climat et efficacité énergétique Synthèse des engagements et résultats de la France. Available online : http://www.developpement-durable.gouv.fr/IMG/pdf/Climat_et_PNAEE.pdf

[2] Luis Pérez-Lombard, José Ortiz, Christine Pout A review on buildings energy consumption information Energy and Buildings. Volume 40, Issue 3, 2008, Pages 394 – 398

[3] S.L. Wong, Kevin K.W. Wan, Danny H.W. Li, Joseph C. Lam Impact of climate change on residential building envelope cooling loads in subtropical climates. Energy and Buildings. Volume 42, Issue 11, November 2010, Pages 2098 – 2103

[4] F. Garde, A. Bastide, F Lucas, L. Christie. Improving building design and indoor conditions in the mid-highlands of the French tropical island of La Réunion. Application to a green building high school “Le Tampon Trois Mares”. CLIMA 2007, Helsinki, Finland. Juin 2007

[5] Lucas F., Bastide A., Adelard L., Boyer H., Garde F. Iterative optimisation using simple simulation tools to improve building design in hot and humid climates. The 11th International Conference on Indoor Air Quality and Climate. Copenhagen. 17 – 22 august. 2008.

[6] Garde F., Adelard L., Mara T., Lucas F., Miranville F., Implementation and experimental validation of passive design principles used in naturally ventilated buildings under humid tropical climates., Clima 2000, 13-15 septembre, 2001, Napoli, Italy,

[7] RTAADOM. Règlementation Thermique, Acoustique et Aération. Availbale online : http://www.reunion.developpement-durable.gouv.fr/les_grands_dossiers/reglementation-construction/rtaadom/rtaadom.htm

[8] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings (EPB)

[9] EN 15217, Energy performance of buildings—methods for expressing energy performance and for energy certification of buildings, 2007.

[10] J.L. Míguez, J. Porteiro, L.M. López-González, J.E. Vicuña, S. Murillo, J.C. Morán, E. Granada Review of the energy rating of dwellings in the European Union as a mechanism for sustainable energy . Renewable and Sustainable Energy Reviews, Volume 10, Issue 1, February 2006, Pages 24-45

[11] Chwieduk D. Towards sustainable-energy buildings. Applied Energy, Volume 76, Issues 1-3, September-November 2003, Pages 211-217

[12] Turner Cathy, Mark Frankel, Energy Performance of LEED for New Construction Buildings—Final Report, New Buildings Institute, White Salmon, WA, 2008.

[13] Pérez-Lombard L., Ortiz J., González R.,. Maestre I. R. A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes. Energy and Buildings, Volume 41, Issue 3, March 2009, Pages 272-278.

[14] Richalet V., Neirac F. P., Tellez F., Marco J., Bloem J. J. HELP (house energy labeling procedure): methodology and present results. Energy and Buildings, Volume 33, Issue 3, February 2001, Pages 229-233.

[15] Zmeureanu R., Fazio P., DePani S., Calla R. Development of an energy rating system for existing houses. Energy and Buildings, Volume 29, Issue 2, 1999, Pages 107-119

[16] Lee Siew Eang, Rajagopalan Priyadarsini. Building energy efficiency labeling programme in Singapore. Energy Policy, Volume 36, Issue 10, October 2008, Pages 3982-3992.

[17] Drury B. Crawley, Linda K. Lawrie, Frederick C. Winkelmann, W. F. Buhl, Y. Joe Huang, Curtis O. Pedersen, Richard K. Strand, Richard J. Liesen, Daniel E. Fisher, Michael J. Witte, Jason Glazer. EnergyPlus: creating a new-generation building energy simulation program. Energy and Buildings, Volume 33, Issue 4, April 2001, Pages 319-331

[18] Eurovent, 2006. Eurovent public directory. Available on: http://www.euroventcertification.com/.

[19] F. Garde, A. Lenoir, M. David. Building design and energy performance of buildings in the French island of La Reunion. Feedback and updating of the PERENE project. REHVA world congress clima 2010, Anatalaya, Turkey (2010)

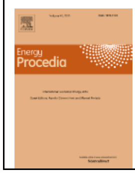
[20] Le calcul simplifié des charges de climatisation - Méthode COSTIC. 1995

[21] Mara T. A., Fock E., Garde F., Lucas F., Development of a new model of Single-Speed Air Conditioners at Part-Load Conditions for Hourly Simulations., International Journal of Solar Energy Engineering, Vol.127, 2005, p.294-301.

[22] Garde F., Lauret A.P., Bastide A., Mara T., Lucas F., Development of a nondimensional model for estimating the cooling capacity and electric consumption of single speed split-systems incorporated in a building thermal simulation program. ASHRAE Transactions, Vol.HI-02-18-3, juin, 2002, p.1128-1143.

[23] Adnot J., Waide .P, Rivière P., Marchio D., Becirspahic S., Lops C., Blanco I., Perez-Lombard L., Ortiz J., Papakontantinou N., Doukas P., JopBenke G., Giraud D. Energy efficiency and certification of central air conditioners (EECCAC). Final report, vol. 2, Ed. Armines, Paris, France; 2003. p. 8–22.

[24] Joshua D. Rhodes, Brent Stephens, Michael E. Webber. Using energy audits to investigate the impacts of common air-conditioning design and installation issues on peak power demand and energy consumption in Austin, Texas.Energy and Buildings, Volume 43, Issue 11, November 2011, Pages 3271-3278



Biography

Franck Lucas is now researcher at the GEPASUD laboratory of the University of French Polynesia. He was researcher at the PIMENT Laboratory until august 2014 and developp a research actitity on renewable energy and building design for tropical area.

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