Isadora Pauli Custódio

ANALYSIS OF TECHNICAL AND ECONOMIC FEASIBILITY OF A MINI SOLAR PHOTOVOLTAIC GENERATOR INTEGRATED ON UNIVERSITY CAMPUS BUILDING ENVELOPES

Master Thesis

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To my son, João Augusto.

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“I don’t want to be interesting. I wan’t to be good.”
(Mies Van Der Rohe, 1955)

RESUMO

Sistemas de energia solar fotovoltaica (FV) podem ser melhor integrados em edifícações, respeitando a arquitetura original ou mesmo sendo considerados durante o projeto de um novo edifício. O desafio para os projetistas é criar um compromisso entre a arquitetura do prédio e a função de gerar energia nas construções. Além dessas questões técnicas, é importante que os projetos levem em conta um estudo dos aspectos econômicos, uma vez que a determinação do valor de bens é tão relevante quanto sua produção física. Este trabalho define um método para selecionar fachadas e coberturas de edifícios, apropriadas para a integração de sistemas fotovoltaicos conectados à rede, no campus sede da Universidade Federal de Santa Catarina (UFSC) em Florianópolis-SC. Para serem aceitos, os sistemas fotovoltaicos devem ter um impacto positivo na arquitetura dos edifícios, além de gerar energia. Ainda, os sistemas devem ser economicamente viáveis. A análise econômica baseou-se no cálculo do Valor Presente Líquido (VPL), da Taxa Interna de Retorno (TIR), do Tempo Descontado de Retorno (DPBT) e do Custo Nivelado de Energia (LCOE). A ideia foi criar um minigerador fotovoltaico com capacidade instalada de 1 MWp, utilizando apenas fachadas e coberturas de edifícios da UFSC, e avaliar o impacto que a energia produzida por este gerador possui no consumo da Unidade Consumidora (UC) Cidade Universitária da UFSC. Os resultados mostraram que as integrações dos módulos FV as fachadas (em forma de *brise soleil* e fachadas ventiladas) e as coberturas trouxeram benefícios estéticos e de conforto térmico e visual para as 6 edificações escolhidas para este estudo. Se apenas as fachadas fossem consideradas, a análise econômica não seria atrativa, mas com a adição das coberturas os sistemas tornaram-se economicamente viáveis. Com a instalação do mini gerador de 1 MWp, o consumo anual de energia da universidade seria reduzido em até 7.42%. Portanto, este estudo demonstrou que é importante que os projetistas estejam cientes das possibilidades, funcionalidade e integração dos sistemas fotovoltaicos e sua oportunidade de serem economicamente viáveis.

Palavras-chave: Sistemas fotovoltaicos integrados a edificações. Fachadas solares. Coberturas solares. Análise econômica de sistemas fotovoltaicos conectados à rede elétrica.

RESUMO EXPANDIDO

Introdução

Existem várias maneiras de produzir eletricidade, cada uma com suas vantagens e desvantagens. A tecnologia solar fotovoltaica (FV) é uma das formas mais proeminentes na atualidade e consiste no uso de módulos FV que convertem diretamente a luz solar em energia elétrica. Uma das grandes vantagens desta forma de geração de energia é poder integrar-se em edifícios, utilizando os módulos FV superpostos à arquitetura existente, bem como substituindo materiais de revestimento ou vedação. Diversos trabalhos foram realizados para estudar e aprimorar os dispositivos utilizados na geração de energia elétrica a partir da irradiação solar (CHALASANI; CONRAD, 2008; KAHOULI-BRAHMI, 2008; TOLEDO et al., 2010; FAHRENBRUCH; BUBE, 2012; GRAU et al. ., 2012). No entanto, não se tem dado muita atenção à questão da poluição visual e, em particular, ao impacto na arquitetura dos edifícios quando da instalação dos módulos FV.

O papel do arquiteto, engenheiro ou designer na integração de módulos FV é manter um compromisso entre a forma dos edifícios e a função dos sistemas FV (RÜTHER, 2004; URBANETZ; ZOMER; RÜTHER, 2011; ZOMER et al., 2013). O núcleo de qualquer atividade arquitetônica está no ato de construir (ZUMTHOR, 2009), por isso é fundamental que as interferências sejam feitas por um profissional da construção civil, já que este é capaz de integrar a plasticidade da forma, a qualidade do espaço e os requisitos técnicos e funcionais da construção. O problema é que, devido à falta de conhecimento, esse profissionais muitas vezes se recusam a usar sistemas FV em seus projetos. O medo de comprometer a geração de energia ao inovar na maneira como os módulos são instalados, ou que os módulos comprometam a estética arquitetônica são as principais causas dessa falta de interesse.

Além disso, um projeto de arquitetura e/ou engenharia depende não somente de soluções técnicas, mas também de soluções econômicas, ambientais, políticas e culturais. Determinar o valor de bens e serviços em termos econômicos é tão importante quanto produzi-los através das leis da física (CÔRTES, 2012). Portanto, é essencial que os projetistas conheçam os indicadores econômicos de um investimento, como o Valor Presente Líquido (VPL), a Taxa Interna de Retorno (TIR), o Tempo de Retorno Descontado (DPBT) e o Custo Nivelado de Energia (LCOE). Infelizmente, um projeto técnico nem sempre está associado a uma análise econômica, o que muitas vezes significa que o projeto é tecnicamente viável, mas economicamente inviável, e o projetista nem percebe isso.

Este trabalho, então, propõe analisar os compromissos entre a forma, a função e os aspectos econômicos dos sistemas FV integrados a edificações e à rede elétrica pública no Brasil, para mostrar e incentivar os profissionais da construção civil a utilizar cada vez mais a tecnologia FV em seus projetos. O estudo de caso consiste nos edifícios existentes em um campus universitário localizado em clima subtropical, através da integração de módulos FV nas fachadas e coberturas desses edifícios.

Objetivos

O objetivo geral desta dissertação é qualificar e quantificar superfícies verticais (fachadas) e coberturas adequadas para a integração de sistemas fotovoltaicos (FV) conectados à rede no campus principal da Universidade Federal de Santa Catarina (UFSC), localizado na cidade de Florianópolis, Brasil (27° S, 48° O).

Os objetivos específicos são:

1. Definir critérios para a aceitação de fachadas e coberturas para a integração de sistemas FV conectados à rede, com base na análise de viabilidade técnica, ou seja, os sistemas FV propostos, além de gerar energia, devem trazer alguma contribuição arquitetônica para os edifícios.
2. Definir critérios para a aceitação de fachadas e coberturas para a integração de sistemas FV conectados à rede, com base na análise de viabilidade econômica, que consiste em cálculos do Valor Presente Líquido (VPL), Taxa Interna de Retorno (TIR), Tempo de Retorno Descontado (DPBT) e Custo Nivelado de Energia (LCOE).
3. Selecionar fachadas e coberturas dos prédios da UFSC pertencentes à Unidade Consumidora (UC) Cidade Universitária, que atendam aos critérios de aceitação estabelecidos, até que a área requerida para a instalação de um mini gerador FV de 1 MWp seja atingida.
4. Simular a produção de energia do mini gerador e avaliar seu impacto na redução do consumo de energia da UC.

Metodologia

O papel dos projetistas é utilizar a tecnologia fotovoltaica (FV) para enriquecer uma arquitetura nova ou existente. A harmonização dela com os edifícios pode conferir mais qualidade estética, e até melhorar o conforto ambiental das edificações através da criação, por exemplo, de *brise soleil* ou fachadas ventiladas.

Para a aprovação das propostas técnicas, a integração FV deve mostrar um compromisso entre o espaço arquitetônico, o formato da edificação e do sistema FV e a função de geração de energia.
A seleção dos prédios foi baseada principalmente em análises de sombreamento. O *software* Ecotect Analysis foi utilizado para gerar máscaras de sombreamento para as coberturas e fachadas norte, leste e oeste dos edifícios e para quantificar o sombreamento causado pelos elementos do entorno construído, segundo Zomer (2014). Um critério de aceitação foi estabelecido para escolher as superfícies que seriam parte deste trabalho. Para serem aceitos, os sistemas FV de cobertura poderiam ter um máximo de 10% de sombreamento anual, e as fachadas norte e leste/oeste, no máximo 17,4%/ano e 18,2%/ano, respectivamente.
A seleção dos edifícios também foi baseada na diversidade de integração FV. Para tornar o estudo mais rico, edificações que aceitassem diferentes tipos de integração FV foram escolhidas.
Finalmente, elementos de vegetação foram incluídos e uma nova análise de sombreamento foi feita, desta vez usando o *software* PVsyst. O mesmo critério de aceitação foi utilizado.
A análise econômica contou com o estabelecimento de um fluxo de caixa e com o cálculo dos indicadores econômicos Valor Presente Líquido (VPL), Taxa Interna de Retorno (TIR), Tempo de Retorno Descontado (DPBT) e Custo Nivelado de Energia (LCOE).
A Taxa Mínima de Atratividade (TMA) foi utilizada nos cálculos. Assim, mudanças no valor do dinheiro ao longo do tempo foram consideradas. Duas taxas foram utilizadas: 4,48%/ano, que é a taxa atual de rendimento da poupança no Brasil, e 3,00%/ano, que é a taxa de juros estabelecida por um programa de financiamento para energias renováveis criado pelo Banco Nacional do Desenvolvimento (BNDES). (BCB, 2017; BNDES, 2017).
Neste trabalho, todas as despesas foram calculadas de acordo com a potência instalada de cada sistema FV, conforme segue:
a) CAPEX: R$3,00/Wp, R$4,00/Wp e R$5,00/Wp, considerando a intensa redução de custos na geração de energia solar FV;
b) Reposição de equipamentos: substituições de inversores a cada 10 anos, cada uma tendo um custo de 21% do investimento inicial (INSTITUTO IDEAL, 2018);
c) OPEX: 1% do investimento inicial a cada ano (LACCHINI; RÜTHER, 2015).
Como as estruturas metálicas de suporte representam 10% do custo total de um sistema FV, 10% do CAPEX foi subtraído quando a análise econômica de uma fachada estava sendo feita. Então, R$135/m², que

representa o custo das estruturas metálicas de suporte nas fachadas, foi adicionado ao CAPEX.
A única entrada do fluxo de caixa é a geração anual multiplicada pela tarifa de energia, ou seja, quanto será economizado na conta de energia elétrica, já considerando as variações da tarifa ao longo dos anos e a taxa de degradação na geração de sistemas FV.
Para o cálculo da geração estimada de energia foi utilizado o *software* PVsyst.
Como a geração de energia solar ocorre durante o dia, foi utilizada a tarifa de energia elétrica fora do horário de pico de R$0,31068/kWh, estabelecida pela companhia de energia elétrica local (ANEEL, 2017b).
Foi utilizada uma taxa de degradação de geração energética de 1,0%/ano, de acordo com os resultados obtidos nos estudos realizados por Limmaneeet al. (2017) para módulos FV de p-Si.
18 cenários econômicos foram considerados, com alterações na TMA, no CAPEX e na variação tarifária anual de energia (4%, 6% e 8% ao ano).
Para serem considerados economicamente viáveis, os sistemas FV devem apresentar um VPL positivo, uma TIR maior que a TMA (4,48% ou 3%), um DPBT menor que a vida útil dos sistemas FV (30 anos) e um LCOE inferior à tarifa de energia elétrica fora do horário de pico (R$0,31068/kWh).
Se um sistema FV completo (fachadas + coberturas) não satisfez os critérios de aceitação, o edifício foi descartado do estudo.
Este procedimento foi realizado até que um gerador de 1 MWp que atendesse aos critérios de aceitação técnica e econômica fosse obtido.
Por fim, comparou-se a geração anual de energia do mini gerador com o consumo da UC, registrado na tarifas de energia elétrica, para ver qual teria sido a redução do consumo naquele ano (agosto de 2017 a julho de 2018) caso os sistemas FV estivessem em operação.

Resultados e Discussão

Todos os sistemas fotovoltaicos (FV) propostos desempenharam um papel na arquitetura do edifício, seja através da melhora dos confortos térmicos e visuais, ou simplesmente não tendo nenhum impacto na arquitetura (o que é um aspecto positivo neste caso, porque significa que os sistemas FV seguiram as formas das edificações).
A análise econômica das fachadas não foi muito atraente, mas com a incorporação de sistemas nas coberturas, os resultados econômicos melhoraram.

A geração total anual de energia foi de 1.144,66 MWh, enquanto o consumo total de energia da UC foi de 15.432,24 MWh e o consumo fora do horário de pico de 14.041,44 MWh.
O mini gerador de 1 MWp reduziria o consumo anual de energia da UC em até 7,42%, com a maior contribuição em janeiro (12,10%) e a menor em abril (5,38%). Se apenas as horas fora do horário de pico fossem consideradas, o consumo de energia seria reduzido em até 8,15%.

Considerações Finais
O estudo mostrou que a instalação de um mini gerador de 1 MWp nas fachadas (pela criação de *brise soleil* e fachadas ventiladas) e coberturas poderia contribuir para o projeto arquitetônico e para o conforto térmico e visual dos edifícios, além de reduzir em até 7,42% do consumo anual de energia da unidade consumidora.
A análise econômica foi feita através do cálculo dos VPLs, TIRs, DPBTs e LCOEs. Foram estudados 18 cenários econômicos para cada edifício, com variações nas TMAs, CAPEXs e variações tarifárias anuais de energia.
A pesquisa mostrou estudos técnicos viáveis para as fachadas, mas a análise econômica não foi muito atrativa. No entanto, com a adição de sistemas nas coberturas, mais casos se tornaram economicamente viáveis e, portanto, atraentes para serem construídos.
Este trabalho demonstrou que é importante que os projetistas estejam cientes das possibilidades, funcionalidade e integração dos sistemas fotovoltaicos (FV) e a oportunidade de serem economicamente viáveis.
Com o custo decrescente dos sistemas FV (INSTITUTO IDEAL, 2018) e o aumento do custo da tarifa elétrica no Brasil (ANEEL 2013, 2014, 2015a, 2016b, 2017b), as fachadas FV devem começar a ser economicamente viáveis em maneiras mais flexíveis. Consequentemente, sistemas FV poderão oferecer soluções atraentes de integração de alta tecnologia e apelo estético, bem como geração de energia renovável e livre de poluição.

Palavras-chave: Sistemas fotovoltaicos integrados a edificações. Fachadas solares. Coberturas solares. Análise econômica de sistemas fotovoltaicos conectados à rede elétrica.

ABSTRACT

Solar photovoltaic (PV) energy systems can be better integrated onto buildings, respecting the original architecture or even being considered during the design of a new building. The challenge for designers is to create a compromise between the architecture of the building and the function of generating energy in those buildings. Besides these technical issues, it is important that the projects take into account a study of the economic aspects, since the determination of the value of goods is as relevant as their physical production. This work defines a method to select appropriated building façades and rooftops for the integration of grid-connected PV systems, on the main campus of *Universidade Federal de Santa Catarina* (UFSC) in Florianópolis-SC. In order to be accepted, the PV systems must have a positive impact on the buildings' architecture on top of generating energy. In addition, the systems should be economic feasible. The economic analysis was based on the calculation of Net Present Value (NPV), Internal Rate of Return (IRR), Discounted Payback Time (DPBT) and Levelized Cost of Energy (LCOE). The idea was to create a photovoltaic mini generator with an installed capacity of 1 MWp using only UFSC buildings' façades and rooftops, and evaluate the impact that the energy produced by this generator has on the energy consumption of UFSC's Consumer Unit (CU) *Cidade Universitária*. Results showed that the integrations of the PV modules to the façades (in the form of *brise soleil* and double-skin façades) and rooftops brought aesthetic, thermal and visual comforts benefits for the 6 buildings chosen for this study. If only the façades were considered, the economic analysis would not be attractive, but with the addition of rooftops the systems became economically viable. With the installation of the 1 MWp mini generator, the university's annual energy consumption would be reduced by up to 7.42%. This study, then, has demonstrated that it is important for building designers to be aware of the possibilities, functionality and integration of PV systems and their opportunity to be economically viable.

Keywords: Building-Integrated Photovoltaic Systems (BIPV). Solar façades. Solar rooftops. Economic analysis of grid-connected photovoltaic systems.

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AC - Alternating current
ANEEL - *Agência Nacional de Energia Elétrica*
Apr - April
Aug - August
a-Si - Amorphous silicon
baht - THB (1 THB = 0.032 USD, in January 16th, 2019)
BAPV - Building-Applied Photovoltaic Systems
BIM - Building Information Modelling
BIPV - Building-Integrated Photovoltaic Systems
BNDES - *Banco Nacional do Desenvolvimento*
CAPEX - Capital expenditure
CDE - *Conta de Desenvolvimento Energético*
CdTe - Cadmium telluride
CELESC - *Centrais Elétricas de Santa Catarina*
CIGS - Copper indium gallium selenide
CNPq - *Conselho Nacional de Desenvolvimento Científico e Tecnológico*
COFINS - *Contribuição para o Financiamento da Seguridade Social*
CONFAZ - *Conselho Nacional de Política Fazendária*
COSIP - *Contribuição para Custeio do Serviço de Iluminação Pública*
CO_2 - Carbon dioxide
CU - Consumer Unit
c-Si - Crystalline silicon
DC - Direct current
Dec - December
DPBT - Discounted Payback Time/*Tempo Descontado de Retorno*
E - East
EDP - *Energias de Portugal*
EVA - Ethylene Vinyl Acetate
€ - EUR (1 EUR = 1.14 USD, in January 16th, 2019)
Feb - February
FV - *Fotovoltaica*
GESTE - *Grupo de Estudos Térmicos e Energéticos*
ICMS - *Imposto sobre Circulação de Mercadorias e Prestação de Serviços*
I_{MPP} - Maximum power point current
IRR - Internal Rate of Return
I_{SC} - Short circuit current
Jan - January
Jul - July

Jun - June
LABSOL - *Laboratório de Energia Solar da Universidade Federal do Rio Grande do Sul*
LCOE - Levelized Cost of Energy/*Custo Nivelado de Energia*
LID - Light Induced Degradation
Mar - March
MARR - Minimum Acceptable Rate of Return
mc-Si - Multicrystalline
mono-Si - Monocrystalline
N - North
Nov - November
NPV - Net Present Value
Oct - October
OPEX - Operating and maintenance expenditures
PIS - *Programa de Integração Social*
P_{MAX} - Maximum output power
PR - Performance Ratio
PV - Photovoltaic
RTE - *Revisão Tarifária Extraordinária*
R&D - Research and Development
R$ - BRL (1 BRL = 0.27 USD, in January 16th, 2019)
S - South
SC - *Santa Catarina*
Sep - September
STC - Standard Test Conditions
$ - USD
TE - Tariff of energy
TIR - *Taxa Interna de Retorno*
TUSD - Tariff of distribution
UC - *Unidade Consumidora*
UFSC - *Universidade Federal de Santa Catarina*
UFRGS - *Universidade Federal do Rio Grande do Sul*
V_{MPP} - Maximum power point voltage
V_{OC} - Open circuit voltage
VPL - *Valor Presente Líquido*
W - West

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1 INTRODUCTION

1.1 JUSTIFICATION AND RELEVANCE OF THE WORK

There are several ways of producing electricity, each having advantages and disadvantages. The solar photovoltaic (PV) technology is one of the most prominent forms today, and consists on the use of photovoltaic modules that directly convert sunlight in electrical energy. One of the great advantages of this form of energy generation is to be able to be integrated on buildings, using the PV modules superimposed on the existing architecture, as well as replacing coating or sealing materials. Several works have been done to study and improve the devices used in the generation of electric energy from solar irradiation (CHALASANI; CONRAD, 2008; KAHOULI-BRAHMI, 2008; TOLEDO et al., 2010; FAHRENBRUCH; BUBE, 2012; GRAU et al., 2012). However, not so much attention has been paid to the issue of visual pollution and in particular to the impact on the architecture of buildings when installing PV modules.

When integrated to the architecture and to the public electricity grid, PV energy has many advantages: it generates energy in a decentralized way and close to its place of consumption, minimizing losses by transmission and distribution; it operates in parallel with large power generating stations and can, therefore, decrease the frequency of blackouts, which in centralized power plants reach a greater number of people; it does not need batteries, because the public power grid plays this role (the excess is injected into the grid and the deficit is supplied by the grid); it does not occupy extra areas, as it is part of the building envelope; and it brings to the buildings an ecological and sustainable image (RÜTHER, 2004; URBANETZ; ZOMER; RÜTHER, 2011; ZOMER et al., 2013). In addition, in commercial, service, institutional and industrial buildings, which are mainly used during the day, there often is a coincidence in the daily hours of maximum demand for electric energy and maximum insolation, that is, the demand is maximum at the same time as the PV system generates more energy (DIDONÉ; WAGNER, 2013).

The role of the architect, engineer or designer in integrating PV modules into buildings is to maintain a compromise between the shape of the buildings and the function of PV systems (RÜTHER, 2004; URBANETZ; ZOMER; RÜTHER, 2011; ZOMER et al., 2013). The core of any architectural activity lies in the act of building (ZUMTHOR, 2009), therefore it is essential that the interferences are made by a construction professional, since this is able to integrate the plasticity of the shape, the quality of the space and the technical and functional requirements of the construction. The problem is that, because of the lack of knowledge, architects, engineers and designers often recuse to use PV systems in their projects. The fear of compromising power generation by innovating in the way PV modules are installed, or the modules compromising the aesthetics of buildings are the main causes of this lack of interest in integrating PV systems on buildings.

In addition, an architectural and/or engineering project relies not only on technical solutions, but also on economic, environmental, political and cultural solutions. Determining the value of goods and services in economic terms is as important as producing them through the laws of physics (CÔRTES, 2012). Therefore, it is essential that designers know the economic indicators of an investment, such as the Net Present Value (NPV), the Internal Rate of Return (IRR), the Discounted Payback Time (DPBT) and the Levelized Cost of Energy (LCOE). Unfortunately, a technical project is not always associated with an economic analysis, which often means that the project is technically feasible, but economically unfeasible, and the designer does not even realize it.

Several studies have been done incorporating not only the technical project of PV systems, but also an analysis of their economic viability.

Evola and Margani (2016) investigated the energetic and economic profitability of the renovation of residential buildings from the 1950s-1990s, located in temperate climates, through the creation of double-skin façades composed of PV modules over the existing sealing material. The analyses were made through variations on the façades' orientations, on the number of floors (from 4 to 10) and on the PV modules' technologies (c-Si, a-Si and CIGS). The results showed that, for an eight-story building with the east-west axis greater than the north-south axis, the DPBT is of approximately nine years, considering the tax incentives in effect during the period of the study and a 50% self-consumption of the electricity produced by the PV modules. It was concluded that greater efficiencies of modules combined with lower prices and higher self-consumption rates could increase the economic profitability of the evaluated systems.

Dávi et al. (2016) carried out simulations of a PV system integrated to the rooftop of a positive-energy building (which injects more energy into the grid than its consumption), in four Brazilian cities. The analyses were done not only on parameters of energy performance, but also on the economic aspects of these systems within the context of electricity compensation. DPBT results were shown for different scenarios of initial investment values and electric energy tariffs. For the city of

Florianópolis, for example, if an initial investment cost of $1.98/Wp (R$7.32/Wp) is adopted, the DPBT can vary from 13 to 31 years. In a more optimistic scenario, with an initial investment cost of $1.08/Wp (R$4.00/Wp), the DPBT can vary from 8 to 13 years.

Limmanee et al. (2017) analyzed the PV degradation rates of different technologies in tropical climate conditions and evaluated the impact of these rates on the LCOEs of PV systems. The degradation of the modules had values between 0.3% and 1.9% per year and the LCOE values, which depend on the module technology and on the degradation rate, were between 4.1 and 14 baht/kWh. It was concluded that, without reducing costs (assuming an initial investment of 70,000 baht/kW, an annual maintenance and operating cost of 700 baht/kW, and an interest rate of 7% per year), the LCOE of PV energy could only approach the electricity tariff if the rate of degradation were of 0.2%/year or less.

Branker, Pathak and Pearce (2011) reviewed the LCOE calculation methodology for PV energy. It was concluded that, with the constant improvement of the PV technology and with favorable financing terms, PV energy may already have LCOEs that are equal to the electric energy tariffs in some places. In addition, with the continued decrease in the cost of PV systems' installation, the increase in the price of grid electricity and the increase in industry knowledge, PV technology could become economically advantageous in future expansion sites.

Sorgato, Schneider and Rüther (2018) analyzed the technical and economic potential of integrating CdTe PV modules on a commercial building façade and rooftop, and evaluated the economic feasibility of replacing traditional façade materials (glass and aluminum composite material) with PV modules, in six Brazilian cities. It was shown that the aluminum composite material has a lower cost than the PV modules (what helps to reduce the investment's initial cost if the material is substituted by the PV modules), while glasses are still more expensive. The results indicated that to replace conventional façade building materials with PV modules is an innovative approach of energy generation with economic benefit.

This work, then, proposes to analyze the compromises between the form, function and economic aspects of PV systems integrated to buildings and to the public electricity grid in Brazil, to show and encourage construction professionals to increasingly use PV technology in their building projects. The case study consists on the existing buildings of a university campus located in a subtropical climate, through the integration of PV modules on the façades and rooftops of these buildings, in the most different ways.

1.2 OBJECTIVES

1.2.1 General objective

The general objective of this master thesis is to qualify and quantify vertical surfaces (façades) and rooftops suitable for the integration of photovoltaic (PV) systems connected to the grid at the main campus of *Universidade Federal de Santa Catarina* (UFSC), located in the city of *Florianópolis*, Brazil (27° S, 48° W).

1.2.2 Specific objectives

This work's specific objectives are:

1. To define criteria for the acceptance of façades and rooftops for the integration of grid-connected PV systems, based on technical feasibility analysis, that is, the proposed PV systems, in addition to generating energy, have to bring some architectural contribution to the buildings.
2. To define criteria for the acceptance of façades and rooftops for the integration of grid-connected PV systems, based on economic feasibility analyses, which consists on calculations of Net Present Value (NPV), Internal Rate of Return (IRR), Discounted Payback Time (DPBT) and Levelized Cost of Energy (LCOE).
3. To select façades and rooftops from UFSC's buildings that belong to the Consumer Unit (CU) *Cidade Universitária*, that meet the acceptance criteria established, until the area required for the installation of a 1 MWp mini generator is reached.
4. To simulate the energy production of the mini generator and evaluate its impact on the reduction of the CU's energy consumption.

2 THEORETICAL FOUNDATION

2.1 PHOTOVOLTAIC SOLAR ENERGY

The generation of electricity, essential to modern society, has been made through several technologies that include thermoelectric generation (e.g. nuclear, coal, gas, oil, biomass, etc.) and hydropower, and more recently wind generation.

A more modern and elegant way of producing energy is through the photovoltaic (PV) effect, whereby, solar cells directly convert the energy of the sun, or solar radiation, into electrical energy without moving parts, without emitting noises or any other type of pollution and using the virtually inexhaustible energy of the sun (RÜTHER, 2004). This can be done by PV systems. These systems are composed of specially designed plates, the PV modules, which contain components that are sensitive to solar irradiation: the PV cells, made with semiconductor materials that, when subjected to sunlight, convert the energy of the light photons directly into electricity.

Each form of electric energy production has advantages and disadvantages that imply several associated costs. There are the environmental costs, that is, the impact that a certain type of generation can have on nature. There are risks associated with harmful radiation to humans, as in the case of nuclear power stations that use nuclear radiation to generate steam. There are issues related to the place where the energy is generated, thus requiring transmission lines to bring this energy to the consumer; and also visual pollution, that is, the impact that the adoption of one or other technology causes in our cities, streets, buildings and landscapes. Poles, cables, transformers and large quantities of power measurers, are part of the daily life so that the necessary electric energy is available; however, there are ways to minimize these elements and leave the landscape unobstructed.

It is believed that the production of electric energy by PV systems has great appeal to the minimization of all these costs:

a) The energy can be generated in a decentralized way and close to its consumption, which minimizes the losses by transmission and distribution (RÜTHER, 2004);

b) When integrated on buildings, PV modules do not occupy extra areas, since they can use existing surfaces or even replace coating or sealing materials (RÜTHER, 2004);

c) Its power generation does not cause noise pollution, since its production is static and silent (RÜTHER, 2004);

d) The maintenance cost is small, since there are no moving parts that need to be lubricated, corrected and monitored;

e) The energy produced and not instantly used can be injected into the public power grid, generating credits to its producer, which can be used when there is no availability of solar irradiation. This strategy is known as energy compensation system, or net metering (ANEEL, 2012);

f) The energy source, the sun, is abundant, and can be considered inexhaustible (RÜTHER, 2004);

g) PV systems can cooperate with large power plants, thus reduce the frequency of blackouts (RÜTHER, 2004);

h) It brings the image, to those who adopt it, of ecological and sustainable awareness;

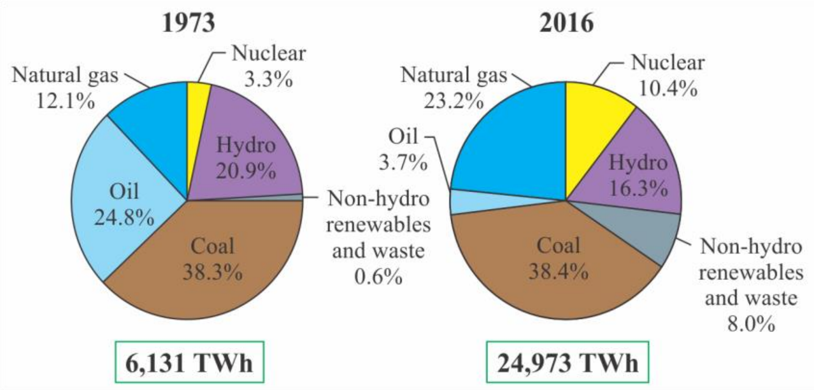
i) In commercial, service, institutional and industrial buildings, mainly used during the day, there is often a coincidence in the hours of maximum demand for electric energy and maximum insolation, that is, the demand is maximum at the same time as the PV system generates more energy (DIDONÉ; WAGNER, 2013). In Brazil, air conditioning loads represent on average 47% of the energy consumption in commercial buildings and on average 48% of the consumption in public buildings (LAMBERTS; DUTRA; PEREIRA, 2014). Therefore, the use of PV systems integrated to buildings can be very useful to reduce the peak energy demand for air conditioning during the day.

2.1.1 Photovoltaic solar energy in numbers

Figure 1 shows that, in 43 years, the global energy production from renewable sources fluctuated from 21.5% to 24.3% in relation to the total energy generation, being the most significant increase in the share of energy produced by non-hydro renewable sources (geothermal, solar, wind, tide/wave/ocean, biofuels, waste, heat and others), which ranged from 0.6% to 8.0% (IEA, 2018). This growth was not only due to the awareness of global warming, but also due to political interests that raised fossil fuel prices and created pollution charges.

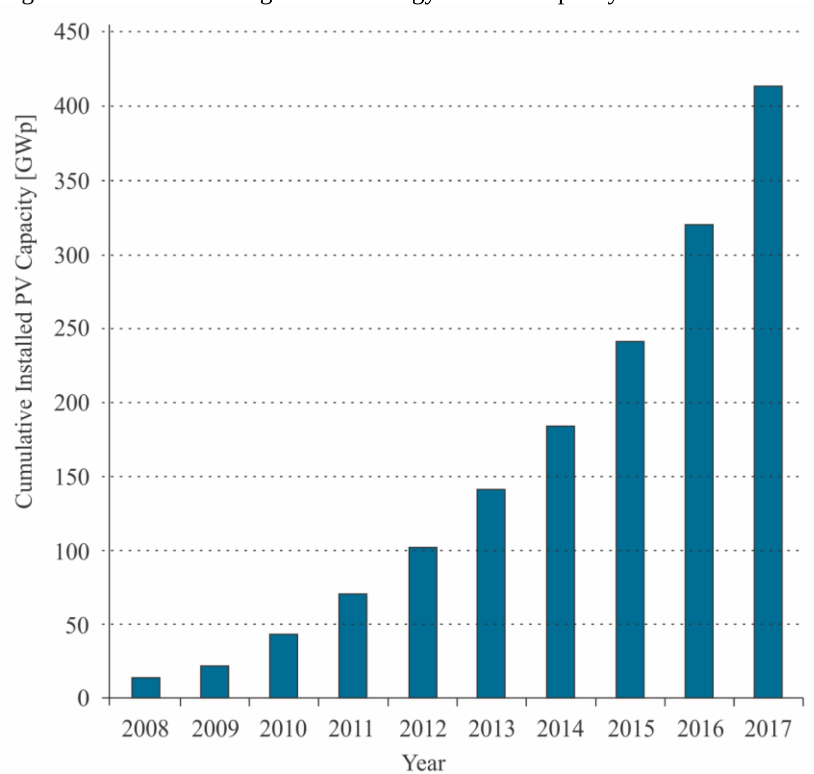
The need to reduce the emission of pollutants combined with technological achievements and social commitment will make PV solar energy one of the most important sources of electricity in the world (CHIVELET; SOLLA, 2007). A rise in the numbers of world PV generation can be seen: it has increased from 4 TWh in 2005 to 328 TWh in 2016 (IEA, 2018). By the end of 2017, the world’s PV systems total installed capacity was 414 GW, compared to only approximately 14 GW in 2008, as shown in Figure 2 (ISE, 2018) and 1 GW in 2000.

Figure 1 - World energy generation by source for the years of 1973 and 2016.



Source: Adapted from Key World Energy Statistics (IEA, 2018).

Figure 2 – Growth of the global PV energy installed capacity.



Source: Adapted from Photovoltaics Report (ISE, 2018).

By the end of 2018, Brazil had 2,259 PV generators, totalizing around 1.50 GWp of installed capacity. This number represents almost 1% of the total installed capacity of the country's power generation enterprises (±160 GWp). In addition, there were 28 (±770 MWp) PV projects under construction and 52 (±1,450 MWp) with construction not yet started (ANEEL, 2018). These numbers show that there is a growing tendency to use the sun as an energy source in the country.

2.2 SOLAR RADIATION

On the Earth's surface, solar radiation depends on the geographic location and on the slope and orientation of the plane that is receiving it, as well as issues related to the local climate (RÜTHER, 2004), that is, solar irradiation reaches all regions of the planet in a non-uniform way.

Global irradiation is the name given to all the radiation that reaches a certain surface, or the sum of direct and diffuse irradiation. Direct irradiation is one that reaches a surface directly from the sun. On the other hand, diffuse irradiation reaches a surface after being dispersed by atmospheric molecules and particles.

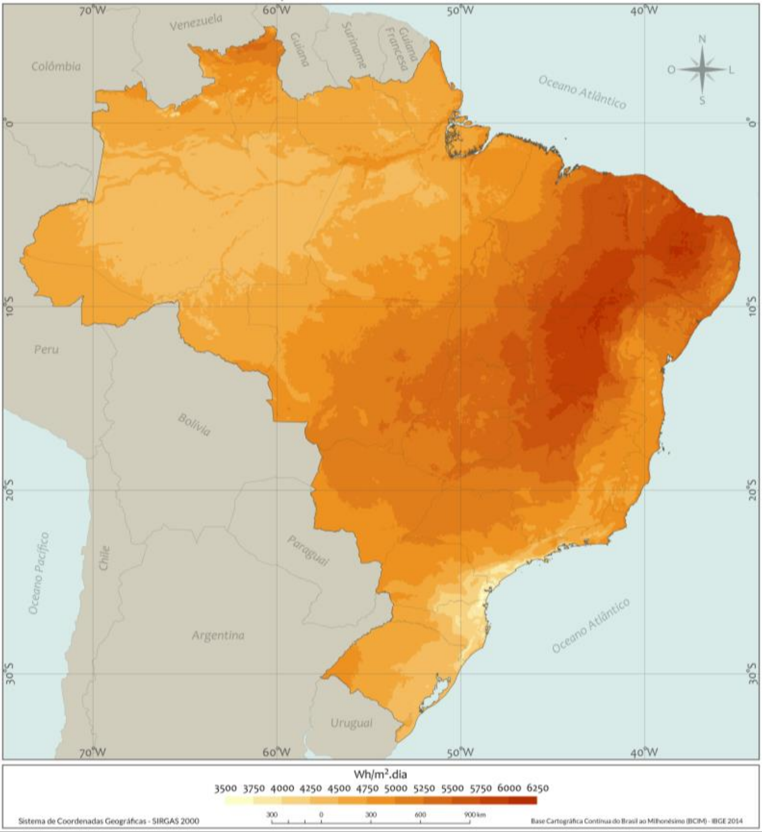
A tilted surface with a slope equal to the local latitude and North oriented (if the surface is located in the Southern Hemisphere) receives the largest possible amount of solar irradiation over a year (HÜSSEIN; AHMAD; EL-GHETANY, 2004; MEHLERI et al., 2010).

In tropical and subtropical countries, such as Brazil, the use of solar energy for electric power generation is quite attractive, since these places have optimal conditions of solar radiation during the entire year.

Figure 3 shows a map with the annual average of the total daily global horizontal irradiation incident in Brazil, and Figure 4 presents a map with the annual average of the total daily radiation incident on a surface that is North oriented and with a slope equal to the local latitude, in Brazil.

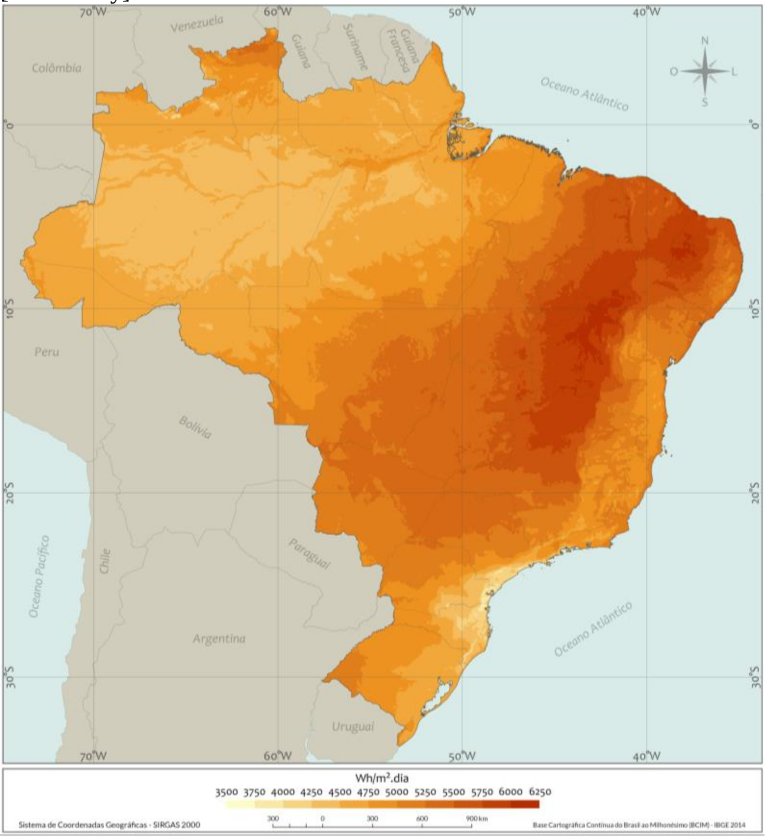
It is possible to observe that the annual average of the total daily global horizontal irradiation is very homogeneous throughout the country, with a maximum value of 6.25 kWh/m² at specific points in the Northeast, where there is low precipitation throughout the year and the annual average cloud cover is the lowest in the country. The city of *Florianópolis* (27° S, 48° W), where this study was carried out, has a well distributed precipitation throughout the year and presents a low annual average of the total daily global horizontal irradiation: approximately 4.25 kWh/m² (PEREIRA et al., 2017). Still, this number is superior to the highest value of the annual average of global horizontal irradiation in the sunniest place in Germany, country that has the 4th highest PV net installed capacity in the world (40.7 GW) (SOLARGIS, 2018; IEA, 2018).

Figure 3 - Annual average of the total daily global horizontal irradiation incident in Brazil, in [Wh/m².day].



Source: 2nd edition of the Brazilian Atlas of Solar Energy (PEREIRA et al., 2017).

Figure 4 - Annual average of the total daily radiation incident on a surface that is north oriented and with a slope equal to the local latitude, in Brazil, in [Wh/m².day].



Source: 2nd edition of the Brazilian Atlas of Solar Energy (PEREIRA et al., 2017).

2.3 INSTALLATION OF PHOTOVOLTAIC SYSTEMS

The installation of a PV system consists not only of the PV modules and a fixing system for them, but also on all the equipment and wiring that will allow the system to be connected to the batteries or to the public electricity grid: DC-AC converter system (or inverter), by-pass diodes and blocking diodes, fuses and circuit breakers, electrical cables, terminals, overvoltage and lightning protection and connection boxes (RÜTHER, 2004).

PV modules can be installed on the ground, where they are mounted on metal structures, or integrated onto buildings, on rooftops and/or façades.

When integrated to buildings, PV modules act as an architectural element at the same time as electric energy generators. The architect or designer can create different shapes with PV modules, being the most common applications on roofs, façades, footbridges, windows, *brise soleil*, carports, double-skin façades (ventilated façades), balconies and skylights.

The integration of PV modules on buildings can be divided in two types: Building-Applied Photovoltaic Systems (BAPV) e Building-Integrated Photovoltaic Systems (BIPV). BAPV is a retrofit, where the PV modules, in addition to not replacing sealing/coating materials, can be installed on the building with different characteristics from those of the existing sealing surface (orientation and/or slope), aiming at the function of the PV system, which is to generate the maximum amount of energy. In BIPV, the integration of the system is thought from the beginning of the project and the PV modules are installed on the building (or even replacing its sealing material) with the same characteristics of the construction (orientation and slope). Therefore, there is a greater compromise between the architectural form and PV system's function.

The role of an architect is to use PV energy to increase the quality of an existing or new architecture, to create harmony between PV technology and buildings, to improve internal environments of buildings by creating PV *brise soleil* or by replacing sealing/coating materials with PV modules, in addition to establishing a compromise between the architectural space, the form and the function of the PV system. The objective is to show that, when there is such a commitment, energy losses must always be calculated and can, in many cases, be considered acceptable (RÜTHER, 2004; URBANETZ; ZOMER; RÜTHER, 2011; ZOMER et al., 2013).

In addition, PV systems can be installed isolated or connected to the public electricity grid.

In isolated systems (off-grid) the generated energy is stored in a battery bank, to be later consumed. This type of installation is usually used in locations that are far from urban centers, where there is no public infrastructure for the supply of electricity. Figure 5 shows the operation of an isolated PV system integrated to buildings.

On the other hand, systems that are connected to the public grid (on-grid) do not require battery banks, since they use the grid itself to store the generated energy. When the system generates more energy than the demand, the excess is injected into the grid, creating an energy credit that can later be consumed; when it generates less, the power grid supplies the deficit. This type of strategy is called net metering and relies on a bidirectional energy meter, in which case the price of the PV system's generated energy is considered to be the same as the one of the energy sold by the electric utility. Figure 6 shows the operation of a grid-connected PV system integrated to buildings.

Figure 5 – Isolated (off-grid) PV system.

Source: *Tudo Sobre Energia Solar: Tipos de Sistema (*On-Grid *e* Off-Grid*)* (ENEL SOLUÇÕES, 2016). Legend: (1) PV modules; (2) inverter; (3) bidirectional counter clock; (4) monitoring; (5) charge controller; (6) battery bank.

Figure 6 – Grid-connected (on-grid) PV system.

Source: *Tudo Sobre Energia Solar: Tipos de Sistema (On-Grid e Off-Grid)* (ENEL SOLUÇÕES, 2016). Legend: (1) PV modules; (2) inverter; (3) bidirectional counter clock; (4) monitoring.

2.3.1 Existing photovoltaic systems at UFSC's main campus

Object of this work, UFSC's main campus already counts with some BAPV and BIPV installations.

The first PV system was installed in 1997 and was also the first grid-connected system in the country. It is located at the rooftop/North façade of the Mechanical Engineering building, North oriented and with a slope of 27°. It is composed by amorphous silicon (a-Si) PV modules (55 opaque modules and 13 semi-transparent ones), reaching an installed capacity of 2 kWp. Figure 7 shows a picture of the system.

Figure 7 – Mechanical Engineering building's PV system.

Source: *Laboratório Fotovoltaica/UFSC*'s website (www.fotovoltaica.ufsc.br).

Other three PV systems are located at the university's Culture and Events Center.

The first one was installed in 2004 and is located at the building's rooftop, North oriented and with a slope of 27°. It is a grid-connected system composed by 80 flexible a-Si PV modules that reach an installed capacity of 10.24 kWp. Figure 8 shows a picture of the system.

The second Culture and Events Center PV installation was built in 2007 and is located at the building's North façade, with a slope of 90°. It is an isolated system, used for the building's emergency lights. It has the shape of a flower and is composed by 6 a-Si PV modules that reach a total installed capacity of 384 Wp. Figure 9 shows a picture of the system.

The third Culture and Events Center PV installation is also an isolated PV system, and was built in 2005. It has the function to load a battery bank that charges electric motorcycles. It is a curved rooftop that comes out of the building's North façade, composed by 6 a-Si PV modules that reach an installed capacity of 408 Wp. Figure 10 shows a picture of the system.

UFSC also counts with two identical outdoor living spaces that are covered by PV modules. One of them is located at the university's hospital and the other one at the university's elementary/high school. Both were built in 2009 and count with 15 microcrystalline silicon (μc-

Si) PV modules that reach an installed capacity of 2 kWp. Figure 11 shows a picture of the school PV system.

Figure 8 – Culture and Events Center rooftop PV system.

Source: *Laboratório Fotovoltaica/UFSC*'s website (www.fotovoltaica.ufsc.br).

Figure 9 - Culture and Events Center North façade PV system.

Source: *Laboratório Fotovoltaica/UFSC*'s website (www.fotovoltaica.ufsc.br).

Figure 10 – Culture and Events Center curved rooftop PV system.

Source: *Laboratório Fotovoltaica/UFSC*'s website (www.fotovoltaica.ufsc.br).

Figure 11 – UFSC's outdoor living space covered by PV modules.

Source: *Laboratório Fotovoltaica/UFSC*'s website (www.fotovoltaica.ufsc.br).

Also interesting to be shown is a PV carport that charges electric vehicles. It is composed by 15 copper indium gallium diselenide (CIGS) PV modules that play the role of the carport's coating material. It has an orientation is 27° E, a slope of 10° and an installed capacity is of 1.80 kWp. Figure 12 shows a picture of the system.

Figure 12 – PV carport to charge electric vehicles.

2.4 REGULATION OF PHOTOVOLTAIC GENERATION IN BRAZIL

In order to encourage the growth of the implementation of distributed PV energy in Brazil, the *Agência Nacional de Energia Elétrica* (ANEEL) approved Normative Resolution No. 482/2012 (ANEEL, 2012). This resolution established the general conditions for access to microgeneration (up to 100 kWp) and minigeration (from 100 kWp to 1 MWp) to electricity distribution systems and made possible the installation of PV systems and the use of the generated energy by any person, being also allowed to connect them to the public electricity grid through the net metering system. With this strategy, it is possible to inject the produced energy excess into the grid and receive compensation from the energy distributor, that is, the utility will charge only the difference between the energy consumed and the energy introduced into the grid. If the amount of injected energy is greater than the one consumed in the same month, the surplus can be used to reduce future consumption of the same consumer unit.

In 2015, ANEEL approved Normative Resolution No. 687/2015, modifying parts of Resolution No. 482/2012 (ANEEL, 2015b). Generation plants characterized as distributed microgeneration have now an installed capacity of less than or equal to 75 kWp, and those characterized as distributed minigeneration, from 75 kWp up to 5 MWp. Within the energy compensation system, three new strategies were introduced: remote self-consumption, shared generation and generation in condominiums. In remote self-consumption, the generated credits can be used in other consumer units, as long as they are in the same distributor area service and in the name of the same owner. In shared generation, consumers can form a consortium or cooperative to share the generated energy. Finally, generation in condominiums allows the division of the PV system's generated credits among the condominium owners.

2.5 PERFORMANCE OF PHOTOVOLTAIC SYSTEMS

The factors that have influence on the performance of PV systems are the irradiance, that is, the geographic location of the building and the positioning of the PV system (orientation and slope), the presence or absence of shading, the temperature and cleaning conditions of the PV modules, the mismatch between panels of the same PV series (string) and the resistances of the conductors.

A PV generator presents optimum efficiency when installed with the surface facing the equator (geographic North for a system located in the Southern Hemisphere), and tilted according to the local latitude (HUSSEIN; AHMAD; EL-GHETANY, 2004; MEHLERI et al., 2010). In an existing building, this is not always possible. However, several studies show that the lost power generation from a non-optimum PV system may be acceptable within certain limits of azimuthal deviation and slope when there is a compromise between the shape of the building and the generating function of the PV system integrated to it (URBANETZ; ZOMER; RÜTHER, 2011; ZOMER et al., 2013).

Shading on PV modules can be caused by built elements from the surroundings or from the building itself and/or by vegetation. Ideally, a system should be homogeneously illuminated, but since this is not always possible, the designer must think about the system's strings in order to minimize the impact of this shading on the system as a whole, since the most shaded PV cell is the one that will determine the current and the power of all parts of the system that are connected in series to this cell.

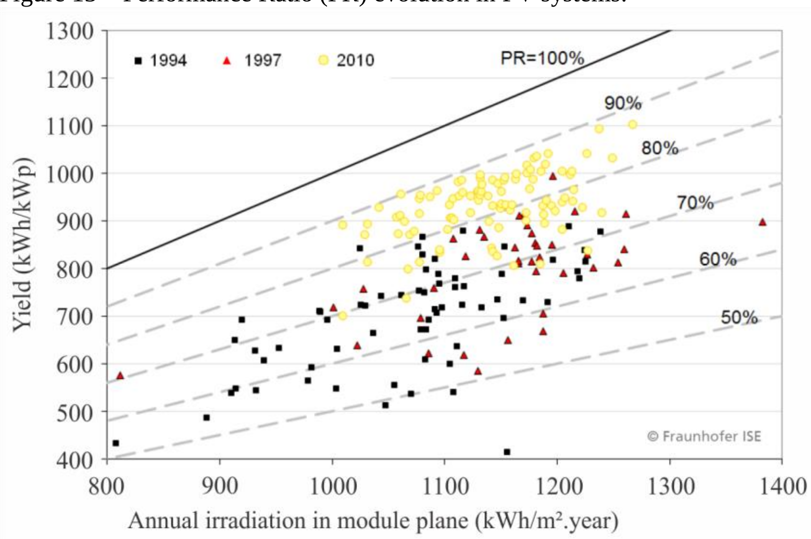
Regarding the temperature of the modules, manufacturers normally recommend that if there is a surface (slab, roof tiles, etc.) for the installation of the PV system, it is good to keep a distance of at least 10 cm between this surface and the modules, so that there is a minimally adequate ventilation under them, what should minimize heating.

For a good cleansing of the modules with rainwater, manufacturers usually recommend a minimum slope of 10°.

For the quantification and evaluation of the PV system's performance, the yield, which is the total energy generated in a certain period in relation to the nominal power of the system [kWh/kWp], is used.

Another widely used index is the Performance Ratio (PR), given in percentage (%). This rate corresponds to the yield in relation to the incident annual irradiation on the system's modules. Its values have grown considerably over the years due to the improvement of PV engineering. Figure 13 shows the evolution of PR by the demonstration of values from the years of 1994, 1997 and 2010. It can be seen that in the 90's a typical PR would be of approximately 70%. With the current technology, PRs of up to 90% can be reached, being the most common in the range of 80-90% (ISE, 2018; REICH et al., 2012).

Figure 13 – Performance Ratio (PR) evolution in PV systems.



Source: Adapted from Photovoltaics Report (ISE, 2018).

2.6 ELECTRICITY TARIFF

The electricity tariff of the final consumer in Brazil is regulated by ANEEL. It is calculated from the generation, transmission and distribution of energy costs, in addition to stipulated expenses with sector charges and taxes. The energy tariff charged from the final consumer is, therefore, the sum of all these costs (ANEEL, 2016a).

In recent years, tariff variations have been mainly due to changes in the costs of energy purchase, energy transmission and sector charges.

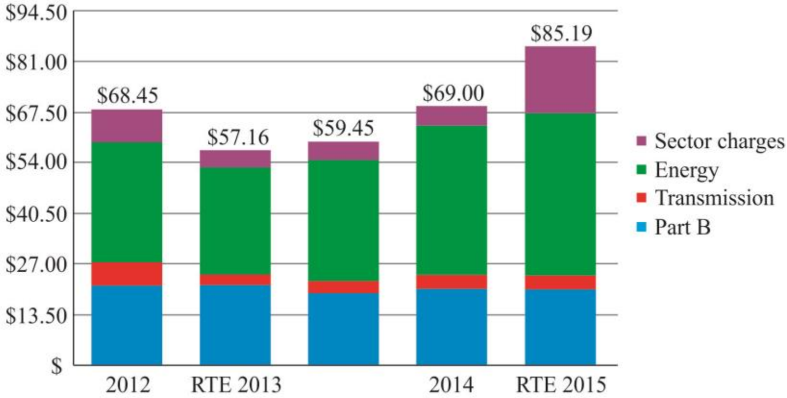
In 2013 and 2014, tariff reductions due to a *Revisão Tarifária Extraordinária* (RTE) reflected in generation and transmission concessions renewals and in the direct contribution from *Tesouro Nacional* resources to the *Conta de Desenvolvimento Energético* (CDE). At the same time, due to the unfavorable hydrological scenario and to the involuntary exposure of the distributors to the short-term market, extraordinary measures were instituted, what allowed the anticipation of resources to the distributors and the postponement of energy costs transference to the tariffs.

In 2015, in addition to a new RTE for tariff increase, tariff flags were created with the objective of covering the generation costs associated with unfavorable hydrology. In the same year, the *Tesouro Nacional* no longer contributed with resources to the CDE and the tariffs began to count with part of the energy costs from 2013 and 2014 (ANEEL, 2016a).

Thus, an average electricity bill in Brazil, which was of $68.45 (R$253.52) in 2012, decreased to $57.16 (R$211.71) in early 2013 after the RTE. With the increase in the energy production cost in 2013 and 2014, it increased to $69.00 (R$255.56). In 2015, after the new RTE, it increased to $85.19 (R$315.53) (ANEEL, 2016a). Figure 14 shows the evolution of the average electricity tariff in Brazil from 2012 to 2015, without taxes.

The costs with energy purchase and transmission plus sector charges (part A) represent 53.5% of the tariff costs, followed by tax costs (29.5%) and costs of energy distribution (part B), which represent 17%.

Figure 14 – Evolution of the average electricity bill in Brazil from 2012 to 2015, without taxes.



Source: Adapted from *Por Dentro da Conta de Luz* (ANEEL, 2016a).

2.7 TAXES IN THE ELECTRICITY BILL

The Federal, State and Municipal Governments charge the PIS/COFINS, the ICMS and the COSIP, respectively, in the electricity bill.

The *Programa de Integração Social* (PIS) and the *Contribuição para o Financiamento da Seguridade Social* (COFINS) are taxes charged by the Federal Government, towards the worker, to attend social programs (ANEEL, 2016a).

The *Imposto sobre Circulação de Mercadorias e Prestação de Serviços* (ICMS) is a state tax applied over operations related to the movement of goods and services. The amount of this tax is charged with a greater weight than its nominal rate, since it is applied not only over the energy consumption, but also over other taxes.

With the aim of encouraging distributed generation, in 2015 was created the *Convênio* ICMS 16/2015 from *Conselho Nacional de Política Fazendária* (CONFAZ). It exempts the tax payment on the surplus electricity generated by distributed generation systems. Thus, the tax is applied only on the energy that the consumer receives from the electricity grid, being discounted the part that it returns to it.

Lastly, the *Contribuição para Custeio do Serviço de Iluminação Pública* (COSIP) establishes as responsibility of the municipalities the design, implementation, expansion, operation and maintenance of public lighting installations.

2.8 TARIFF FLAGS

In Brazil, the Tariff Flags System was implemented in 2015 and counts with four modalities that indicate whether there will be an increase in the value of the energy, depending on the conditions of electricity generation. With the lack of rain and empty reservoirs, for example, hydroelectric plants lose their generation capacity and it is necessary to take energy from another place, in this case, thermoelectric plants, whose energy generation is much more expensive.

The system is divided into four categories. The first one is the green flag, which indicates favorable conditions of energy generation, that is, no extra charges on the electricity bill. The yellow flag indicates less favorable generation conditions, or an addition of $0.0027 (R$0.010) per consumed kWh in the energy bill. Red flag 1 represents more costly generation conditions, that is, an addition of $0.0081 (R$0.030) per consumed kWh in the energy bill. Finally, red flag 2 represents even more costly generation conditions, or an addition of $0.014 (R$0.050) per consumed kWh in the energy bill (ANEEL, 2017a).

This shows one more advantage of PV decentralized generation, because since it occurs close to its place of consumption and is possessed by the CU's owner, it does not suffer impact from the Tariff Flags System.

2.9 PHOTOVOLTAIC MODULES' GLOBAL MARKET

Energy generator systems that use fossil fuels produce large amounts of carbon dioxide (CO_2), a major greenhouse gas. Moreover, they have a great influence on international geopolitical issues, what causes several conflicts, since the availability of each source does not correspond to the demand of each place. Thus, from the popularity that global warming, caused by the greenhouse effect, has gained in recent decades, and from the need to diversify the energy mix of each country, the search for renewable energy sources has been growing.

The world market for PV energy has grown quite rapidly: the average annual growth rate from 2010 to 2017 was 24%. The largest producers of PV modules are China and Taiwan (70%), followed by Central and East Asia (14.8%). The United States and Canada contribute with 3.7% of the world production and Europe with 3.1% (ISE, 2018).

The most commercialized technologies are crystalline silicon (c-Si), which correspond to 95% of the world production of PV modules, with multicrystalline silicon (mc-Si) technology representing 62% of c-Si's total production. Thin films represent only 5% of the total world production (ISE, 2018). This is due to the great availability of the raw material for the manufacture of silicon modules, since the material is abundantly found in many regions of the planet.

Regarding the efficiency of the PV modules, laboratory records are of 26.7% for monocrystalline silicon (mono-Si), 22.3% for multicrystalline silicon (mc-Si), 22.9% for copper indium gallium diselenide (CIGS) and 21% for cadmium telluride (CdTe). Inverters already have a minimum efficiency of 98%, on average (ISE, 2018).

About the prices for purchase and installation of PV systems, in Germany a system of 10 to 100 kWp integrated to the rooftop of a building in the year of 2016 cost on average 1.27 €/Wp. In 1990, this value was of 14.00 €/Wp, that is, in 16 years the price of a PV system decreased on about 91%. The PV modules have had a cost reduction of approximately 10 times in the last 10 years (ISE, 2018).

2.10 COST OF PHOTOVOLTAIC SYSTEMS IN BRAZIL

Prices for acquisition and installation of PV systems in Brazil are constantly falling. These prices have a common characteristic, which is their reduction with the increase of the installed capacity.

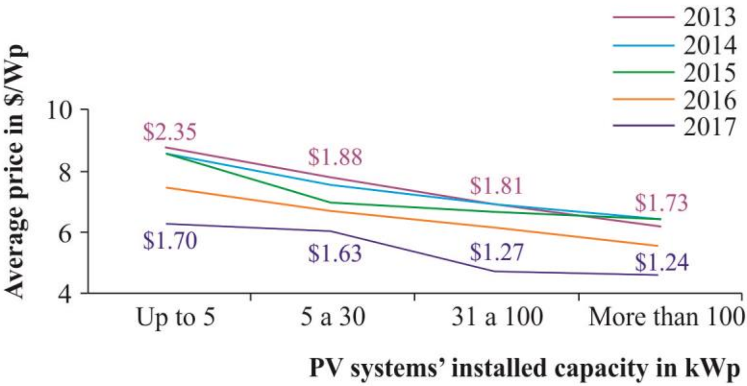
Figure 15 shows the average price of PV systems by power range, for the years of 2013 to 2017, obtained from price quotes made with companies offering turn-key PV installations, and Figure 16 shows the average price by power range, for the year of 2017, obtained from price quotes made with manufacturers/resellers of PV modules and/or inverters.

From 2013 to 2017, the price of a small system of up to 5 kWp dropped by approximately 28%. The other power ranges' prices have also dropped. This was mainly due to the decrease in the price of imported components, annual inflation and changes in the exchange rate (INSTITUTO IDEAL, 2018).

It is important to mention that these annual studies are rapidly outdated because the cost reduction is as intense as the one currently seen in PV solar generation. A quick prices survey in the Brazilian market reveals that currently a small residential generator (installed capacity of less than 5 kWp) already costs about $1.35/Wp (R$5.00/Wp).

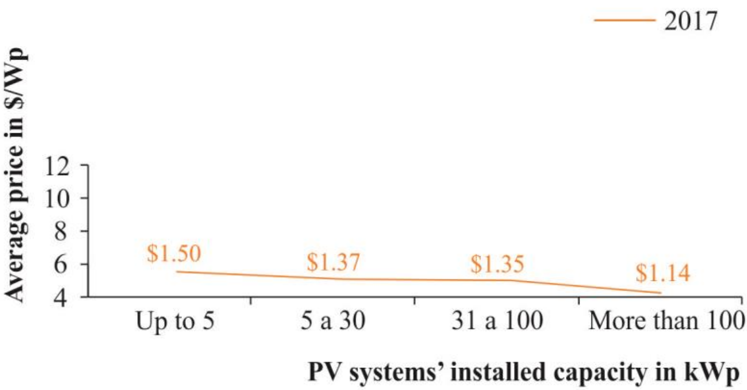
It is possible to notice that the average price of the installers is around 12% higher than that of the manufacturers/resellers of modules and/or inverters. This happens because those who sell the material to the installers are the manufacturers/resellers.

Figure 15 – Average price of PV systems by power range, from the years of 2013 to 2017, obtained from turn-key PV installation companies.



Source: Adapted from *O Mercado Brasileiro de Geração Distribuída Fotovoltaica* (INSTITUTO IDEAL, 2018).

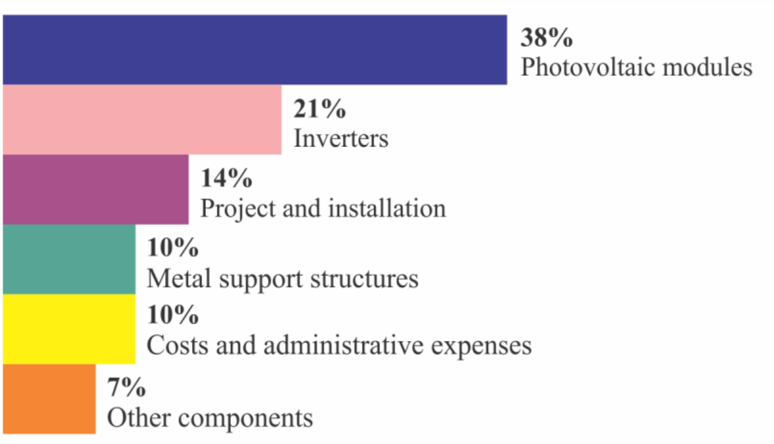
Figure 16 – Average price of PV systems by power range, for the year of 2017, obtained with manufacturers/resellers of PV modules and/or inverters.



Source: Adapted from *O Mercado Brasileiro de Geração Distribuída Fotovoltaica* (INSTITUTO IDEAL, 2018).

The composition of these prices in relation to the required components for the installation of PV systems can be seen in Figure 17. PV modules represent the most expensive component (38%). Next are inverters (21%), project and installation (14%), metal support structures (10%), costs and administrative expenses (10%) and, finally, other components such as installations and electrical projections (7%) (INSTITUTO IDEAL, 2018).

Figure 17 – Composition of the total cost of a PV system.



Source: Adapted from *O Mercado Brasileiro de Geração Distribuída Fotovoltaica* (INSTITUTO IDEAL, 2018)

2.11 CHAPTER'S CLOSURE

This chapter has discussed some relevant subjects for the understanding of this work.

It has shown the importance of diversifying the energy matrix and how decentralized PV systems can contribute to that. Important to understand were the possibilities of integrating PV to buildings and what affects the performance of a system.

Also, the chapter has shown Brazil's advantages in relation to solar radiation values, the country's PV generation regulation and characteristics of the electricity tariffs.

When referring to PV market, it has shown global and Brazilian data, demonstrating that the price of PV systems are decreasing not only in the world, but also in the country where this study was done.

All these topics are important to better understand and justify characteristics and decisions of the technical proposes and economic analysis made in this study.

3 METHODOLOGY

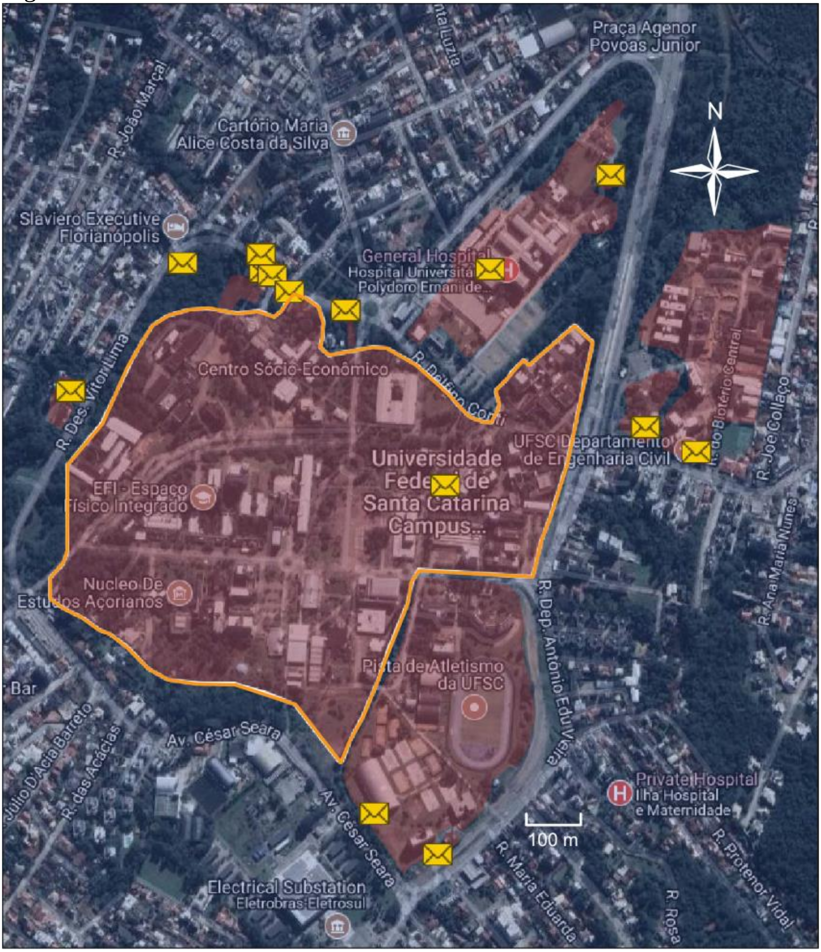
3.1 UFSC'S ELECTRICAL CONTEXT

From August 2017 to July 2018, UFSC had 85 Consumer Units (CUs), of which 25 belonged to the A4 subgroup (supply voltage from 2.3 kV to 25 kV; UFSC's being 13.8 kV), with contracts for the supply of electric energy with the local energy distributor (*Centrais Elétricas de Santa Catarina* - CELESC) in the green horosazonal tariff modality, where a single demand rate (kW) is established and consumption tariffs (kWh) vary according to the time of day (peak or off-peak time).

Of these 25 CUs, those located in *Florianópolis* accounted for 95% of the total consumption, of which 60% was represented only by CU *Cidade Universitária*.

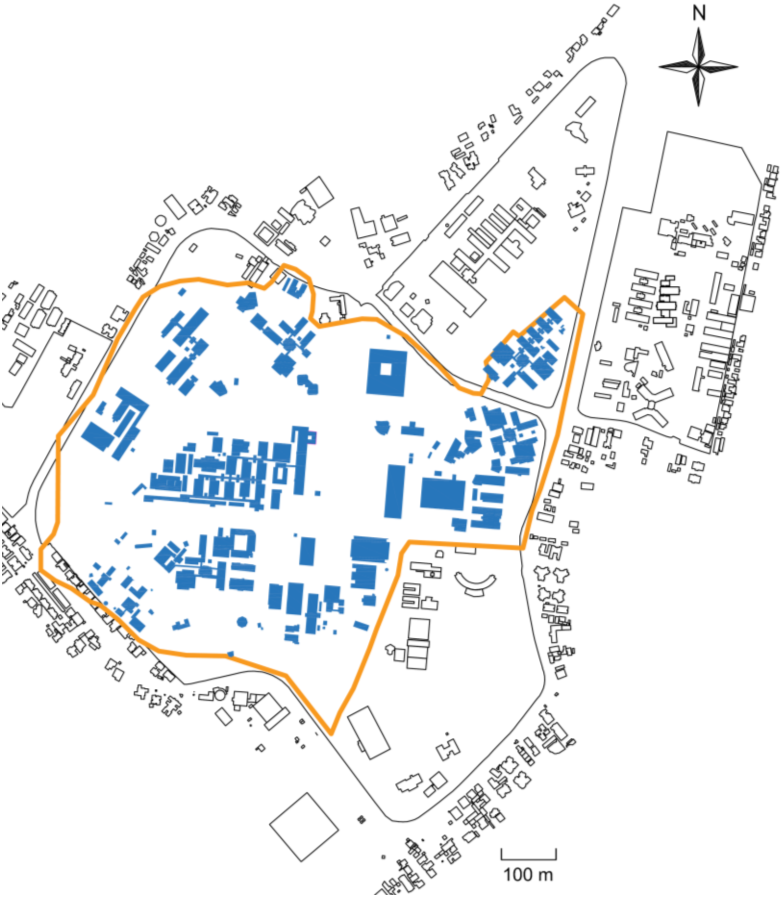
CU *Cidade Universitária*, object of this study, occupies 58% of the total area of *Campus Reitor João David Ferreira Lima*, main campus of the university, located in the city of *Florianópolis* (27° S, 48° W). Figure 18 shows the area covered by this CU, which is approximately 490,000 m², and Figure 19 shows its built area (in blue), composed by 255 different rooftops, that is, approximately 96,400 m² (20% of its total area).

Figure 18 – CU *Cidade Universitária*'s area.



Source: Adapted from *Localização das faturas de energia elétrica* (DPAE, 2017).

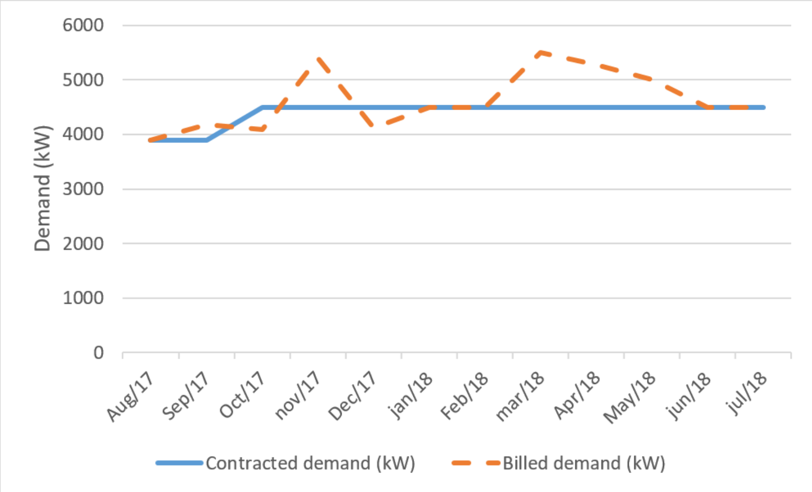
Figure 19 – CU *Cidade Universitária*'s built area (in blue).



3.1.1 Electric energy bills

From August 2017 to July 2018, CU *Cidade Universitária* had different contracted monthly demands with CELESC, and in some months it was also charged for exceeded demand. Figure 20 shows the contracted and billed monthly demands.

Figure 20 – CU *Cidade Universitária*’s contracted and billed monthly demands.



Source: Monthly electricity bills from CU *Cidade Universitária* (CELESC 2017; 2018).

The CU had an annual electricity consumption of approximately 15.43 GWh and electric energy expenses of approximately $2.59 million (R$9.61 million), as shown in Table 1.

In the energy bills, in addition to peak and off-peak consumption, expenses with contracted demand, ICMS and COSIP are recorded. During the analyzed period, the value of ICMS charged from UFSC was of 25% per month and of COSIP, $53.57 (R$198.41) per month. Since UFSC is a federal institution, it is exempted from federal taxes on the electricity bill.

Depending on the situation, UFSC may also be charged for exceeded peak and off-peak reactive energy, exceeded demand, additional in months of yellow or red tariff flags and penalties for late payment of previous bills.

Table 1 – Consumption and expenses with electric energy of the CU *Cidade Universitária* from August 2017 to July 2018.

Month	Consumption (kWh)		Expenses ($)
	Peak	Off-peak	
Aug/2017	122,735	1,080,185	185,926.57
Sep/2017	119,674	1,151,513	212,492.09
Oct/2017	118,353	1,138,697	216,006.60
Nov/2017	114,914	1,278,702	251,585.22
Dec/2017	98,520	1,216,241	212,171.44
Jan/2018	81,069	949,750	160,949.55
Feb/2018	84,599	1,022,466	170,791.62
Mar/2018	153,340	1,518,052	274,086.27
Apr/2018	153,896	1,460,578	256,797.11
May/2018	134,286	1,238,967	240,144.97
Jun/2018	103,700	1,015,482	208,242.98
Jul/2018	105,706	970,811	204,901.83
Total	**1,390,792**	**14,041,444**	**2,594,096.24**
	15,432,236		

Source: Monthly electricity bills from CU *Cidade Universitária* (CELESC 2017; 2018).

3.1.2 Increase in the electricity tariff

CELESC's annual tariff adjustment takes place in August of each year. Table 2 shows, for the period of August 2013 to August 2018, the respective tariffs of distribution (TUSD) and energy (TE) systems, which compose the demand (TUSD) and energy tariffs at peak and off-peak hours (TUSD + TE), without taxes, for the A4 subgroup of the green horosazonal tariff modality.

In the state of *Santa Catarina* (SC), where the city of *Florianópolis* is located, the peak period starts at 6:30 p.m. and goes until 9:30 p.m, that is, PV systems generate energy mainly during off-peak hours. Therefore, in this work, three rates of off-peak hours' tariff variations were used: 4%, 6% and 8% per year.

Table 2 – A4 subgroup’s tariffs of the green horosazonal tariff modality, without taxes.

Period	Demand ($/kW)	Energy ($/kWh)	
		Peak	Off-peak
Aug/2013 – Aug/2014	2.15	0.22624	0.04965
Aug/2014 – Aug/2015	2.14	0.22696	0.05312
Aug/2015 – Aug/2016	2.46	0.29260	0.08692
Aug/2016 – Aug/2017	2.45	0.28142	0.08134
Aug/2017 – Aug/2018	3.42	0.31220	0.08388

Source: *Resoluções homologatórias de Revisão Tarifária Periódica* (ANEEL, 2013; 2014; 2015a; 2016b; 2017b).

Interesting to notice is that the PV systems will be generating energy during the hours of highest energy demand in the university (since the buildings are mostly used during the day). This will contribute to reduce the peak of energy demand.

On the other hand, demand peak hours do not coincide with the electricity tariff peak hours. Something to think about, then, are the disadvantages of installing a distributed energy generation system that will not contribute to the hours where the electricity tariff is higher.

3.2 PHOTOVOLTAIC SYSTEMS’ TECHNICAL PROPOSAL

3.2.1 Technical proposals’ acceptance criterion

The role of building designers is to use PV to enrich an existing or new architecture. The harmonization of PV technology and buildings can give more quality a rooftop or façade aesthetically, and even improve the building’s internal environmental comfort by the creation of, for example, PV *brise soleil* or double-skin façades.

For their approval, then, the façades and rooftops PV integration technical proposals should show a commitment between the architectural space, the building’s and the PV installation shape, and the function of generating energy.

3.2.2 Selection of buildings

The selection of buildings for this study was mainly based on shading analyses. First, CU *Cidade Universitária*’s land and buildings were 3D modeled in the software SketchUp. Next, buildings with façades that have a maximum of 5° azimuthal deviation were selected. Finally, the software Ecotect Analysis was used to generate shading masks for the rooftops and for the North, East and West façades of these buildings and to quantify the shading caused by surrounding constructed elements, according to Zomer (2014). Buildings with that azimuthal characteristic that were shorter than neighboring buildings located on their northern, eastern and western directions were discarded from the study before the software shading analysis, because their rooftops and façades are obviously shaded during the entire day.

SketchUp is a well known software from Google. It is a 3D modeling computer program that can be used for architectural, interior design, landscape architecture, civil and mechanical engineering, film and video game design drawing applications (GOOGLE, 2017).

Ecotect Analysis is a sustainable building design tool from Autodesk. It offers a wide range of simulation and building energy analysis to help improve the performance of buildings. It contains tools such as Solar Analysis, Sun and Shadow Studies, Daylighting and Lighting, Thermal performance, Whole building energy analysis, Weather data visualization, and others. Although Autodesk discontinued it in 2015, it is still the only one that generates shading masks and simultaneously quantifies monthly and annual surface shading percentages that correspond to the energy losses of shaded PV systems (AUTODESK, 2015; ZOMER, 2014).

According to Autodesk, the software was discontinued with the objective of maximizing development efforts on Building Information Modelling (BIM) and cloud-based solutions for building performance analysis and visualization, by integrating Ecotect's functions in the software Revit, through the plug-ins Solar Analysis, and Sun and Shadow Studies (AUTODESK, 2015).

However, Solar Analysis only allows visualization and quantification of the distribution of solar radiation for specific individual days, and Sun and Shadow Studies only allows the visualization of a surface's shadow, but not its quantification.

Two SketchUp plug-ins were also tested: Shadow Analysis and Solar Energy Analysis. The first one shows the amount of shading hours on a surface only on a particular day of the year. The second one shows the amount of solar radiation incident on a surface only on a particular day of the year.

Besides that, the tools Shading Analysis and Dynamic Overshadowing, available on Dr. Andrew Marsh's website, which is

Ecotect’s creator, were also tested. They create shading masks and quantify annual shading, but for a specific point only, not for an entire surface (MARSH, 2018).

Therefore, since the objective was to generate shading masks to see in which months and times of day the surfaces are most shaded, and, at the same time, quantify the surface’s annual shading, Ecotect was still used in this work.

An acceptance criterion was established to choose the buildings’ surfaces that would be part of this work, based on the amount of annual average of incident radiation on each surface and on the fact that 10% of annual shading on ideal positioned PV systems, calculated by Ecotect, correspond to 10% of energy losses at this latitude (ZOMER, 2014).

In order to be accepted, it was decided that rooftop PV systems could have a maximum of 10% annual shading. Since North façades receive 63% of the annual average of incident radiation of what an ideal PV rooftop system receives at this latitude, East and West façades receive 59%, a proportion calculation was made to establish the maximum acceptable annual shading percentage on the façades. The results showed that it would be allowed a maximum shading of 17.4%/year and 18.2%/year for North and for East/West façades, respectively.

The selection of buildings was also based on PV integration diversity. To make a richer study, buildings that accepted different kinds of PV integration were chosen:

a) A building that, because of the shading analysis, would allow only rooftop PV integration;

b) Another one that would allow only North façade and rooftop integration;

c) One that would allow only East façade, West façade and rooftop integration;

d) Another one that would allow North façade, one of the lateral (E or W) façades and rooftop integration;

e) One that allowed North, East and West façades plus rooftop integration;

f) Also, buildings that would ask for *brise soleil*, and ones that would enable the creation of double-skin façades by substituting its original coating material.

The different possibilities are enough to represent all kinds of PV integration that could be created at the university’s buildings. PV layouts were made until an installed capacity of 1 MWp was reached and accepted in technical and economic aspects.

Finally, vegetation elements were included and a new shading analysis was done for the chosen surfaces, this time using PVsyst's tool "Detailed, according to Module Layout", which considers the shading according to the electrical strings of the system. The same acceptance criterion was used.

3.2.3 Photovoltaic modules

Double-glass multicrystalline silicon (mc-Si) PV modules were chosen for many reasons. First, the double-glass configuration is very aesthetically pleasing for façades. Also, this technology has the second highest laboratory record efficiency rate (22.3%), falling behind only mono-Si technology (26.7%). However, mc-Si is easier to be manufactured and results in a lower cost PV module.

Interesting to notice is that this is an opaque module, so when integrated to buildings in the shape of *brise soleil*, the need for air conditioning can be decreased, but the need for artificial lighting will automatically increase.

The modules used in the proposed systems are 72-cells, mc-Si double-glass PV modules of 320 Wp (Figure 21). Chart 1 shows their technical specifications and their datasheet can be found in Attachment 1 (BYD, 2017).

Figure 21 – Adopted PV module: BYD Series P6D-36 4BB, 320 Wp.

Source: BYD Series P6D-36 4BB datasheet (BYD, 2017).

Chart 1- Technical specifications of the PV modules.

General characteristics	
Technology	Multicrystalline silicon (mc-Si)
Dimensions	1961 x 985 mm
Thickness	29 mm
Weight	32.9 kg
Number of cells	72
Front cover	3.2 mm tempered glass with anti-glare coating
Encapsulating	Ethylene Vinyl Acetate (EVA)
Frame	No frame
Electrical parameters (STC)	
P_{MAX}	320 W
Eficiency	18.3%
V_{MPP}	36.78 V
I_{MPP}	8.70 A
V_{OC}	46.39 V
I_{SC}	9.15 A
Temperature coefficient of V_{OC}	-0.30 %/°C
Temperature coefficient of I_{SC}	+0.066 %/°C
Cable length	2 x 400 mm

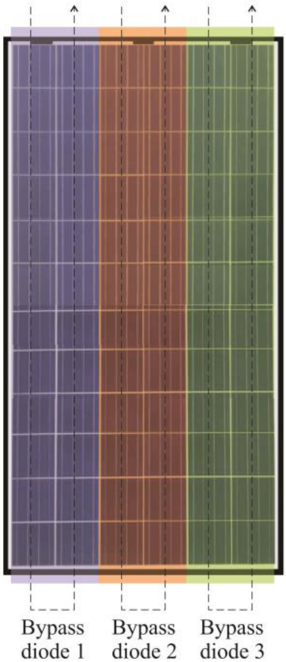
Source: BYD Series P6D-36 4BB datasheet (BYD, 2017).

3.2.4 Photovoltaic modules layout

The PV modules were all portrait-oriented because of their cells' and bypass diodes' (a series of connected cells) configurations. Figure 22 shows the module's 3 bypass diodes.

Because of the layout of the bypass diodes and of the way shading will act on the PV systems, it is better if the PV modules are portrait-oriented so that if one bypass diode is shaded, the module is still going to be generating energy through the other two substrings within the module.

Figure 22 - PV module’s bypass diodes.



Source: Adapted from BYD Series P6D-36 4BB datasheet (BYD, 2017).

3.3 PHOTOVOLTAIC SYSTEMS’ ECONOMIC ANALYSIS

Engineering economics helps professionals in making decisions. It is a discipline that applies methods for the economic evaluation of technically feasible alternatives for engineering projects. It includes four stages: recognition and definition of a problem, identification of viable alternatives, analysis of the alternatives and choice of the best alternative (CÔRTES, 2012).

The purchase and installation of a PV system is very capital intensive, since much of the investment is made at the beginning of the project. Thus, the question that remains is whether, throughout the years, it financially compensates more the purchase of energy from the utility only, or the installation of a grid-connected PV system.

The economic analysis begins from this question, that can be answered by the establishment of a cash flow and the calculation of some economic indicators, such as Net Present Value (NPV), Internal Rate of

Return (IRR), Discounted Payback Time (DPBT) and Levelized Cost of Energy (LCOE). In this work, all these four indicators were used.

The Minimum Acceptable Rate of Return (MARR), which represents the interest rate, was used in the calculation of the economic indicators; thus changes in the value of money over time were considered.

Two values of MARR were used: 4.48%/year, which is the current savings income rate in Brazil, and 3.00%/year, which is the interest rate established by a financing program for renewable energies created by *Banco Nacional do Desenvolvimento* (BNDES) (BCB, 2017; BNDES, 2017).

3.3.1 Cash flow

The cash flow is a necessary tool for financial management and analysis of an investment. It shows the cash balance (incomings less outgoings) of the investment during its entire lifetime. In this work, a PV systems' lifetime of 30 years was considered, since this is the warranty period stipulated by the manufacturer of the PV modules used (BYD, 2017).

The outgoings are the capital expenditure (CAPEX), the equipment replacements and the operating and maintenance expenditures (OPEX), such as routine cleaning of the modules' surfaces, connector status check, replacement of damaged cables, vandalism recovery and restoration of support structures affected by extreme weather conditions. In this work, all the outgoings were calculated according to each PV systems' installed power, as follows:

a) CAPEX: \$0.81/Wp (R\$3.00/Wp), \$1.08/Wp (R\$4.00/Wp), and \$1.35/Wp (R\$5.00/Wp), considering the intense reduction of costs in solar PV hardware;

b) Equipment replacements: inverters' replacements every 10 years, each replacement having a cost of 21% of the initial investment (INSTITUTO IDEAL, 2018);

c) OPEX: 1% of the initial investment every year (LACCHINI; RÜTHER, 2015).

Since metal support structures represent 10% of the total cost of a PV system, 10% of the CAPEX was subtracted when an economic analysis of a façade was being done. Then, \$36.45/m² (R\$135/m²), what represents the cost of façades' metal support structures was added to the CAPEX. This value came from a prices survey in the local market, where there is a company that is recently specializing in façades' metal support structures to PV modules.

It is important to notice that PV systems integrated to buildings are usually located close to the point of energy consumption, thus, costs with transmission and distribution, very common in centralized generator systems, are also reduced.

The only income of the PV systems is the annual energy generation multiplied by the energy tariff, that is, how much will be saved in the electric energy bill, already considering the variations of the tariff over the years and the rate of degradation of the PV systems' generation.

Since solar energy generation occurs during daylight, the current electric off-peak time tariff of $0.08388/kWh (R$0.31068/kWh), established by the local electric power company, was used (ANEEL, 2017b).

A 1.0%/year degradation rate was used, according to results obtained in the studies conducted by Limmaneeet al. (2017) for mc-Si PV modules.

18 economic scenarios were studied, with changes on the MARR, on the CAPEX and on the annual energy tariff variation, as shown in Table 3.

Table 3 – Economic scenarios.

Case	**MARR (%/year)**	**CAPEX ($/Wp)**	**Energy tariff variations (%/year)**
1	4.48	0.81	4
2	4.48	0.81	6
3	4.48	0.81	8
4	4.48	1.08	4
5	4.48	1.08	6
6	4.48	1.08	8
7	4.48	1.35	4
8	4.48	1.35	6
9	4.48	1.35	8
10	3.00	0.81	4
11	3.00	0.81	6
12	3.00	0.81	8
13	3.00	1.08	4
14	3.00	1.08	6
15	3.00	1.08	8
16	3.00	1.35	4
17	3.00	1.35	6
18	3.00	1.35	8

The way annual energy generations were estimated is described in item 3.3.2 of this work.

3.3.2 Energy generation estimation

There are several ways of calculating PV systems' estimated energy generation. In this work, the latest version of the most widely adopted software PVsyst was used.

PVsyst was designed by physicist André Mermoud to enable architects, engineers and researchers to manage grid-connected PV systems projects, as well as to enable the definition of the systems' installed power, its PV modules and inverters (MERMOUD, 2018).

The system location and global horizontal solar irradiance data are specified (the software itself calculates the inclined solar irradiance data from a chosen transposition model and available solar radiation databases). The system's installed capacity, PV modules, inverters and strings are defined. From these data and a 3D modeling of the system and its surroundings (which can be done in the software itself or imported from SketchUp), its energy generation, Performance Ratio (PR) and annual energy yield are calculated.

In addition, the software specifies the system's performance losses, that can be caused by shading, irradiation incidence angle, dirt (soiling), incident irradiance levels, temperature, PV module quality, PV arrangement incompatibility, ohmic losses in cabling, efficiency, nominal power, maximum power, nominal and maximum inverter voltage, and system unavailability.

The climate database for Florianópolis, measured by the Brazilian Atlas of Solar Energy, which was calculated using 17 years of satellite irradiance data, was used (PEREIRA et al., 2017).

Losses due to shading caused by nearby vegetation and neighboring buildings, due to the amount of incident irradiation on the PV array plane, temperature, and PV module and inverter conversion efficiencies were estimated. Shading percentages were calculated using PVsyst's tool "Detailed, according to Module Layout", which considers the shading according to the electrical strings of the system.

A degradation of 1.0% was considered in the energy generation for each of the 30 years of the systems' lifetime (LIMMANEE et al., 2017; BYD, 2017).

The Perez-Ineichen transposition model was used (PEREZ *et al.*, 1987; PEREZ *et al.*, 1990) for the calculation of the inclined plane incident radiation, since this is the model that gives closer results to the values of tilted solar irradiance measured for the city of *Florianópolis* (SANTOS; RÜTHER, 2014).

The PV systems were modeled according to the electrical configuration of their modules and inverters, respecting the arrangement of the modules in the façades and rooftops. Each building's surroundings (other buildings and vegetation) were also modeled with the purpose of calculating the losses in energy generation caused by shadowing.

As losses data, some standard values from the software itself were used, as shown in Table 4.

Table 4 – PVsyst's standard losses data.

Ohmic loss	1.5%
PV module's efficiency loss	0.8%
System unavailability	2.0%

Source: PVsyst (MERMOUD, 2018).

For mismatch losses, a value of 2.0% was used (HICKEL et al., 2014), for soiling, 3.0% (HICKEL et al., 2016), and for LID (Light Induced Degradation), 3.0% (MUNOZ; CHENLO; ALONSO-GARCÍA, 2011).

3.3.3 Net Present Value (NPV)

The Net Present Value (NPV) brings to the initial moment all the investment's cash flow and adds it to the value of the initial investment. It considers the value of money in time, as it uses the MARR. Equation 1 shows how to obtain the NPV.

If the NPV is positive, it means that the investment will have been profitable at the end of its lifetime. Otherwise, if it is negative, it means that it will result in a financial loss.

$$NPV = -C_0 + \sum_{n=1}^{T} \frac{VF_n}{(1+MARR)^n} \qquad \text{(Equation 1)}$$

Where:
NPV = Net Present Value, in \$;
C_0 = initial cost, in \$;
T = total duration, in years;
n = concerned period, in years;

VF_n = values referring to the cash flow for the total duration of the system, in \$;
$MARR$ = Minimum Acceptable Rate of Return, in %.

3.3.4 Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the discount rate that makes NPV zero. It shows the productivity of an investment project, considering the same periodicity of the cash flow, that is, it represents the annual profitability percentage of the project. It is calculated using Equation 2.

$$\sum_{n=1}^{T} \frac{VF_n}{(1+IRR)^n} - C_0 = NPV = 0 \qquad \text{(Equation 2)}$$

Where:
T = total duration, in years;
n = concerned period, in years;
VF_n = values referring to the cash flow for the total duration of the system, in \$;
IRR = Internal Rate of Return, in %;
C_0 = initial cost, in \$;
NPV = Net Present Value, in \$.

3.3.5 Discounted Payback Time (DPBT)

The Discounted Payback Time (DPBT) is the period (n) that zeroes the NPV, or the time that an investment takes to be paid, considering the value of money over time, that is, including the MARR on the calculation. It is represented by Equation 3.

$$NPV = -C_0 + \sum_{n=1}^{T} \frac{VF_n}{(1+MARR)^n} = 0 \qquad \text{(Equation 3)}$$

Where:
NPV = Net Present Value, in \$;
C_0 = initial cost, in \$;
T = total duration, in years;
n = concerned period, in years;
VF_n = values referring to the cash flow for the total duration of the system, in \$;
$MARR$ = Minimum Acceptable Rate of Return, in %.

3.3.6 Levelized Cost of Electricity (LCOE)

The Levelized Cost of Electricity (LCOE) is calculated in order to be compared to the utility's energy tariff. As LCOE considers all the expected costs over the lifetime of a PV system, if its value is lower than the local utility energy tariff, there will be a profit at the end of the system's lifetime. Otherwise, if it is higher than the energy tariff, there will be losses.

Equation 4 presents the formula for calculating the LCOE. Briefly, it can be defined as the system's total lifetime costs divided by the energy generated during that lifetime.

$$LCOE = \left(C_0 + \sum_{n=1}^{T} \frac{C_n.(1+i)^{n-1}}{(1+MARR)^n}\right) \Big/ \sum_{n=1}^{T} \frac{E_{PV}.(1+i)^{n-1}.(1-d)^n}{(1+MARR)^n} \qquad \text{(Equation 4)}$$

Where:
$LCOE$ = Levelized Cost of Electricity, in \$/kWh;
C_0 = initial cost, in \$;
T = total duration, in years;
n = concerned period, in years;
C_n = annual costs for system maintenance, in \$;
$MARR$ = Minimum Acceptable Rate of Return, in %;
E_{PV}= annual PV power generation, in kWh;
i = annual variation of energy tariff, in %;
d = degradation rate of annual energy generation, in %.

3.3.7 Economic analysis' acceptance criteria

In order to be considered economically feasible, the PV systems should have a positive NPV, an IRR higher than the MARR (4.48% or 3%), a DPBT lower than the PV systems' lifetime (30 years) and a LCOE lower than the current electric off-peak time tariff of $0.08388/kWh (R$0.31068/kWh).

If a complete PV system (façades + rooftops) did not satisfy the acceptance criterion, the building was discarded from the study.

This procedure was done until a generator of ~1 MWp that met the technical and economic acceptance criteria was obtained.

3.4 MINI GENERATOR CONTRIBUTIONS TO THE UNIVERSITY

Finally, the estimated 1 MWp mini generator's annual energy generation was compared to the CU's energy consumption registered in the local utility electricity tariffs (CELESC), to see what would have been the reduction in the consumption of that year (August 2017 to July 2018) if the PV systems had been in operation over the corresponding period.

4 RESULTS

4.1 PHOTOVOLTAIC SYSTEMS' TECHNICAL PROPOSAL

This work aims at selecting suitable façades and rooftops of buildings that participate of the CU *Cidade Universitária* for the integration of a 1 MWp PV minigerator. Rooftop PV integration is a very common idea. Façades PV integration, not so much. In this work, some facts have influenced the idea of integrating PV to the buildings' façades.

Due to the university's location, surfaces facing North with a slope of 27° are the ideal ones to optimize a PV system's annual energy generation. PV systems with these characteristics are often installed on rooftops.

Looking at façades at Florianópolis' latitude, then, the ones that are North oriented are the best ones to generate energy. The annual average of incident radiation on these façades corresponds to 63% of the one of an ideal surface.

East and West façades were also considered, because they receive what corresponds to 94% of the annual average of incident radiation on north façades.

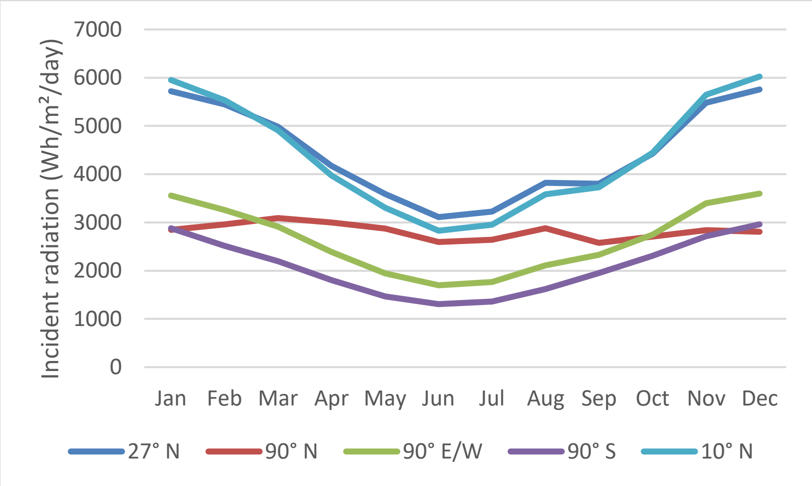
Façades facing South receive only 74% of the annual average of incident radiation on North façades, and that is the reason they have been discarded from this study.

PV systems were also suggested on the rooftops of each building as a strategy to improve the economic results. On rooftops it is possible to integrate PV modules at slopes that vary from 10° N (minimum inclination to keep the PV modules' warranty) to 27° N (ideal inclination to optimize energy generation), which, besides having higher daily average of incident radiation than on façades during a year, also contribute to a lower impact on the buildings' architecture.

Figure 23 shows the daily average of incident radiation for each month of a year, at the city of *Florianópolis*, Brazil, at an ideal surface (27° N), at façades facing North (90° N), East or West (90° E/W) and South (90° S), and at a low tilted North surface (10° N).

It is possible to see that during the warmest months (November, December, January and February) East and West façades receive more radiation than North façades. This way, the façades would be contributing with more energy during the months in which the energy demand is higher. Besides that, the PV modules could work as *brise soleil* by helping to block the heat and the direct sunlight that enter the rooms, and improve the buildings' thermal comfort at the same time as reducing the use of air conditioners.

Figure 23 – Daily average of incident radiation on different surfaces, for each month of a year, at the city of *Florianópolis*, Brazil.



Also, it is possible to conclude that by adding PV modules to rooftops, the PV systems as a whole (façades plus rooftops) will not only generate more energy because it will raise the system's yield (productivity), but also improve the economic feasibility of the systems.

These averages of incident radiation were obtained using the software RADIASOL *Radiação Solar*, which was designed to assist engineers, architects, and other professionals in calculating incident solar radiation on different orientated and inclined surfaces. The software was developed in *Laboratório de Energia Solar* (LABSOL) of the *Grupo de Estudos Térmicos e Energéticos* (GESTE) from *Universidade Federal do Rio Grande do Sul* (UFRGS) (LABSOL/UFRGS, 2001).

The Perez-Ineichen transposition model (PEREZ et al., 1987; PEREZ et al., 1990) was used for the calculation of incident radiation on tilted planes, since this is the model that generates the closest results to the measured values of inclined solar irradiance for the city of *Florianópolis* (low latitude site) (SANTOS; RÜTHER, 2014).

Also interesting to show is a comparison of the annual irradiation means for PV systems located at different sites of the world, at their ideal orientation and inclination to optimize solar energy generation (a tilted surface with a slope equal to the local latitude and North oriented for Southern Hemisphere surfaces or South oriented for Northern Hemisphere surfaces), on façades facing North (for Southern Hemisphere surfaces) or South (for Northern Hemisphere surfaces), and on East or West façades. Figure 24 shows the location of the cities that were chosen for this comparative study.

Figure 24 – Location of the chosen cities.

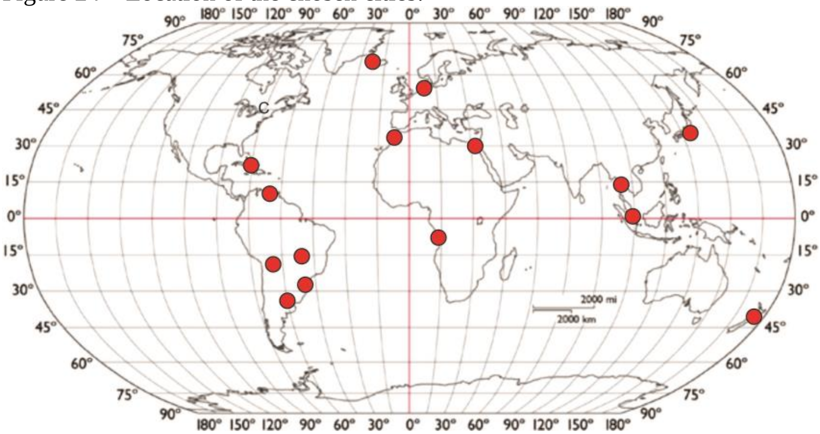


Table 5 shows the global horizontal annual radiation means for each city and annual radiation means for an ideal PV system and for a N/S façade PV system (that is, a surface with a slope of 90°), located at each city. Table 6 shows the global horizontal annual radiation means for each city and the annual radiation means for an ideal PV system and for an E/W façade PV system (that is, a surface with a slope of 90°), located in each of the chosen cities.

The tables also have color scales that go from the highest absolute numbers (darkest yellow, blue and red) to the lowest absolute ones (in white), and the percentages of the façades' annual radiation means in relation to the ideal surfaces' annual radiation means.

It is possible to notice that in some countries such as Canada, Germany, Iceland and Japan, the percentages of the façades' annual radiation means in relation to the ideal surfaces' annual radiation means are high, but the absolute radiation values are low. Other countries such as Angola, Argentina, Bolivia, Brazil, Cuba, New Zealand, Singapore, Thailand and Venezuela have the opposite behavior: while the percentages of the façades' annual radiation means in relation to the ideal surfaces’ annual radiation means are low, the absolute radiation values are high.

Table 5 – Global horizontal annual radiation means and annual radiation means for an ideal PV system and a N/S façade PV system.

Location		**Annual Radiation Means (kWh/m²)**			**% façade/ideal**
Country/ City	**Latitude Longitude**	**Global Horizontal**	**Ideal surface**	**N/S façade**	
Angola/ Luanda	8.82°S 13.22°E	5008	5054	2718	53.78%
Argentina/ Buenos Aires	34.58°S 58.48°W	4327	4652	3079	66.19%
Bolivia/ Sucre	19.02°S 65.27°W	5489	5815	3473	59.72%
Brazil/ Brasília	15.78°S 47.93°W	4928	5175	3235	62.51%
Brazil/ *Florianópolis*	27.59°S 48.00°W	4270	4461	2817	63.15%
Canada/ Ottawa	45.45°N 75.62°W	3864	2259	1232	54.54%
Cuba/ Camaguey	21.40°N 77.85°W	4508	3996	1579	39.51%
Egypt/ Cairo	30.65°N 31.25°E	5589	4091	1394	34.07%
Germany/ Hamburg	53.63°N 10.00°E	2646	1558	1031	66.17%
Iceland/ Reykjavik	64.13°N 21.90°W	2121	1130	846	74.87%
Japan/ Tokyo	35.68°N 139.77°E	2976	2283	1219	53.39%
Morocco/ Rabat	34.00°N 6.83°W	5088	3538	1378	38.95%
New Zealand/ Wellington	41.28°S 174.76°E	3793	4059	2790	68.74%
Singapore/ Singapore	1.37°N 103.92°E	4420	4414	1837	41.62%
Thailand/ Bangkok	13.73°N 100.50°E	4811	4482	1668	37.22%
Venezuela/ Caracas	10.52°N 66.92°W	5552	5327	1838	34.50%

Table 6 – Global horizontal annual radiation means and annual radiation means for an ideal PV system and an E/W façade PV system.

Location		**Annual Radiation Means (kWh/m²)**			**% façade/ideal**
Country/ City	**Latitude Longitude**	**Global Horizontal**	**Ideal surface**	**E/W façade**	
Angola/ Luanda	8.82°S 13.22°E	5008	5054	2957	58.51%
Argentina/ Buenos Aires	34.58°S 58.48°W	4327	4652	2679	57.59%
Bolivia/ Sucre	19.02°S 65.27°W	5489	5815	3132	53.86%
Brazil/ Brasília	15.78°S 47.93°W	4928	5175	2915	56.33%
Brazil/ *Florianópolis*	27.59°S 48.00°W	4270	4461	2642	59.22%
Canada/ Ottawa	45.45°N 75.62°W	3864	2259	2003	88.67%
Cuba/ Camaguey	21.40°N 77.85°W	4508	3996	2134	53.40%
Egypt/ Cairo	30.65°N 31.25°E	5589	4091	2753	67.29%
Germany/ Hamburg	53.63°N 10.00°E	2646	1558	1367	87.74%
Iceland/ Reykjavik	64.13°N 21.90°W	2121	1130	1152	101.95%
Japan/ Tokyo	35.68°N 139.77°E	2976	2283	1451	63.56%
Morocco/ Rabat	34.00°N 6.83°W	5088	3538	2526	71.40%
New Zealand/ Wellington	41.28°S 174.76°E	3793	4059	2421	59.65%
Singapore/ Singapore	1.37°N 103.92°E	4420	4414	2079	47.10%
Thailand/ Bangkok	13.73°N 100.50°E	4811	4482	2272	50.69%
Venezuela/ Caracas	10.52°N 66.92°W	5552	5327	2584	48.51%

By the comparison of the values shown for the city of *Florianópolis*/Brazil, where this study was carried out, with the values for Germany, country that has one of the highest PV net installed capacities in the world, it is possible to see that in *Florianópolis*, the façades' annual radiation means are at least the double of Germany's façades' annual radiation means, even if the percentages of the façades' annual radiation means in relation to the ideal surfaces' annual radiation means are higher in Germany. This fact supports and encourages the idea of integrating PV modules in façades at the city of *Florianópolis*.

The constant reduction in the cost of PV solar generation combined with the increasing costs of civil construction materials also motivated the PV integration on façades, where traditional coating materials can be replaced by PV modules.

4.1.1 Selection of buildings

Figure 25 shows the 3D model made of UFSC's main campus, with CU *Cidade Universitária*'s buildings (in blue).

Figure 25 – UFSC's main campus, with CU *Cidade Universitária*'s buildings (in blue).

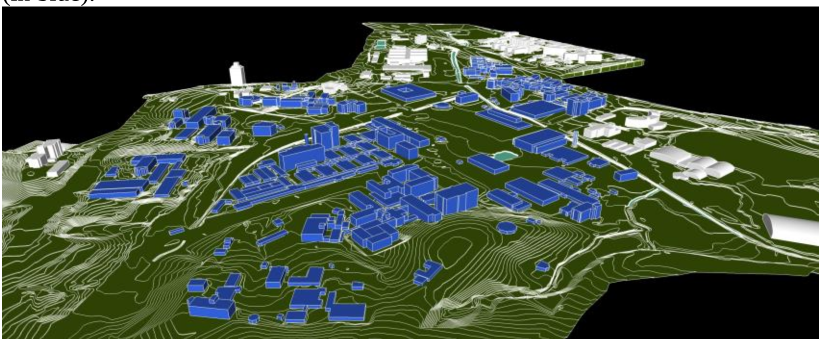
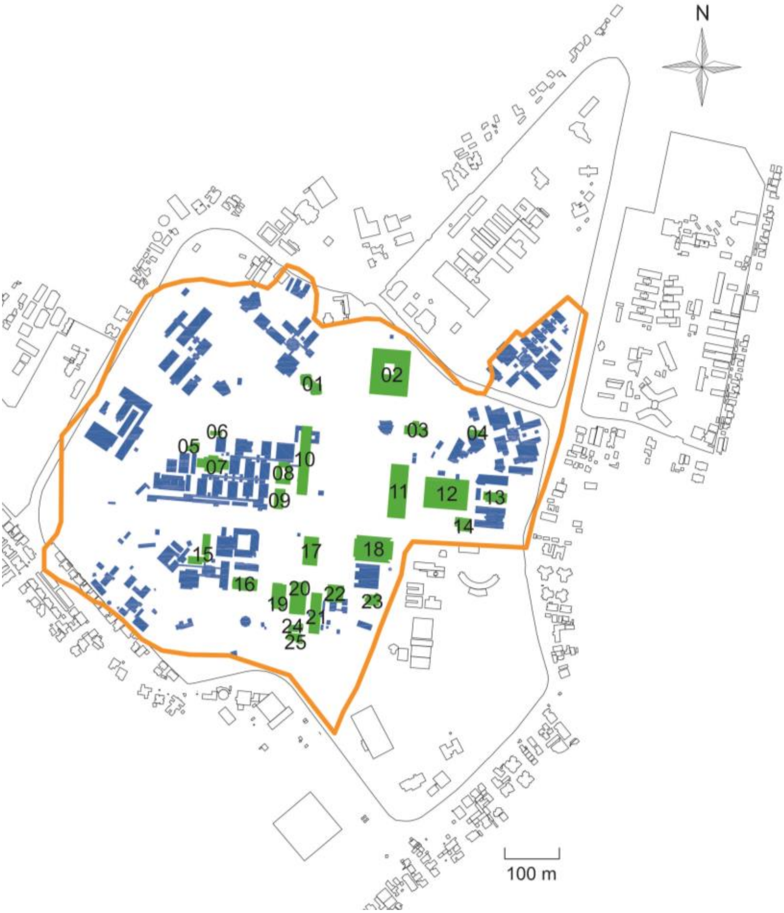


Figure 26 shows the buildings that were considered on the first shading analysis (in green), that is, buildings that have a maximum of 5° azimuthal deviation, and that do not have higher neighboring buildings.

Figure 26 – Buildings considered on the first shading analysis (in green).



For the Ecotect shading analysis, building 01 was divided in 13 surfaces: 3 rooftops, 3 North surfaces, 3 East surfaces and 4 West surfaces. Only the rooftops (annual shading percentages of 7.7%, 0.1% and 9.2%) and one of the North surfaces (annual shading percentage of 15.6%) were accepted by the shading acceptance criterion.

Building 02 was divided in 4 surfaces for its shading analysis: 1 rooftop, 1 North surface, 1 East surface and 1 West surface. All of the surfaces were accepted by the shading acceptance criterion. The rooftop had an annual shading percentage of 2.3%, the North surface of 4.2%, the

East surface of 5.4% and the West surface of 6.6%. Figure 27 shows the rooftop's shading mask, Figure 28, North surface's shading mask, Figure 29, East surface's shading mask, and Figure 30, West surface's shading mask. It is possible to see that the rooftop is shaded only before 6:00 a.m. and after 6:30 p.m. during the whole year; the North surface is shaded in the morning until 9:00 a.m. and in the afternoon from 3:00 p.m., in the months of October, November, December, January, February and March; the East surface is shaded in the afternoon (starting at 12:00 p.m.) during the whole year; and the West surface is shaded in the morning (until 12:00 p.m.) during all year. Some of the most notable shadings are shown in Figures Figure 31, Figure 32, Figure 33 and Figure 34.

Figure 27 – Building 02's rooftop shading mask.

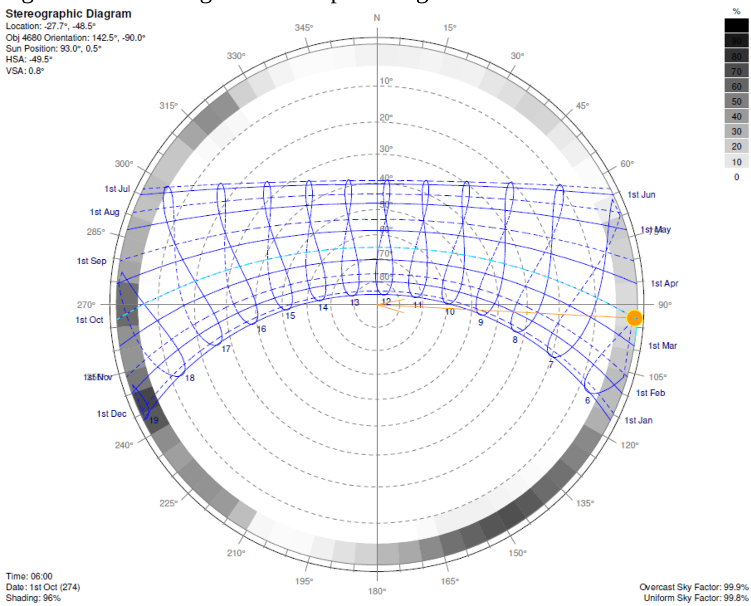


Figure 28 – Building 02's North surface shading mask.

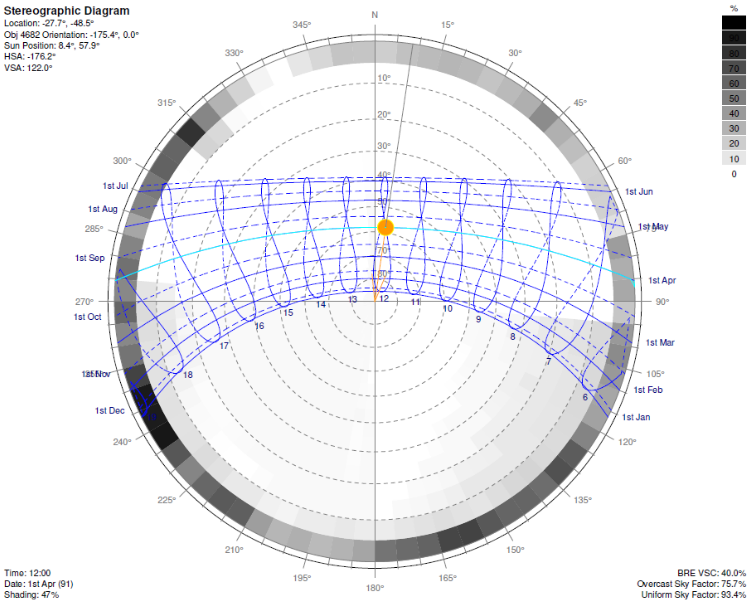


Figure 29 – Building 02's East surface shading mask.

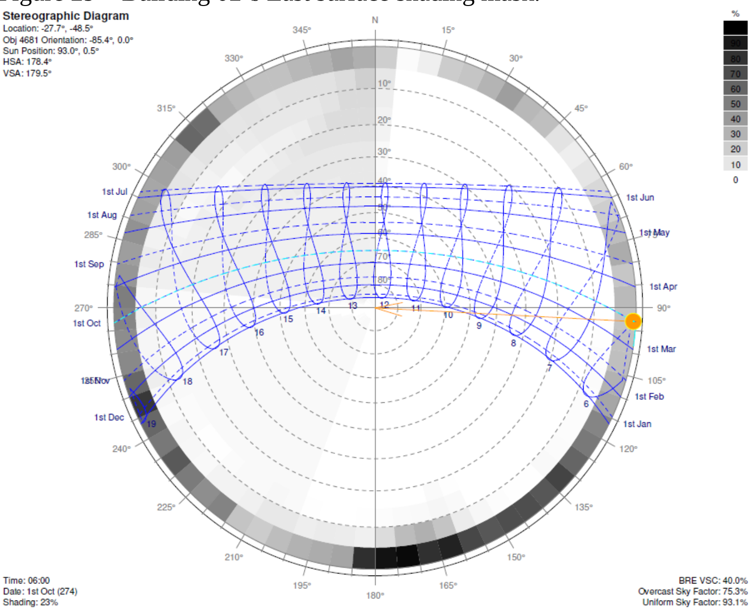


Figure 30 – Building 02's West surface shading mask.

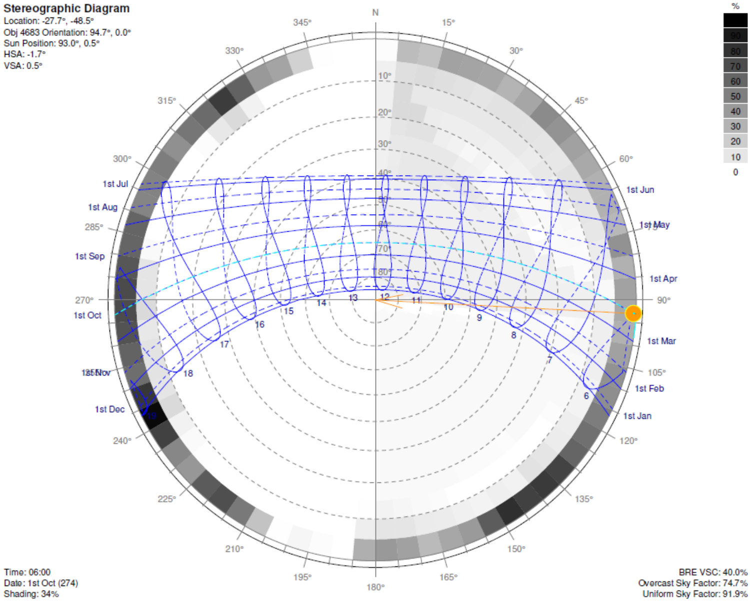


Figure 31 – Building 02's rooftop and N surface shadings at 6:00 a.m. in December.

Figure 32 – Building 02’s rooftop and N surface shadings at 6:30 p.m. in December.

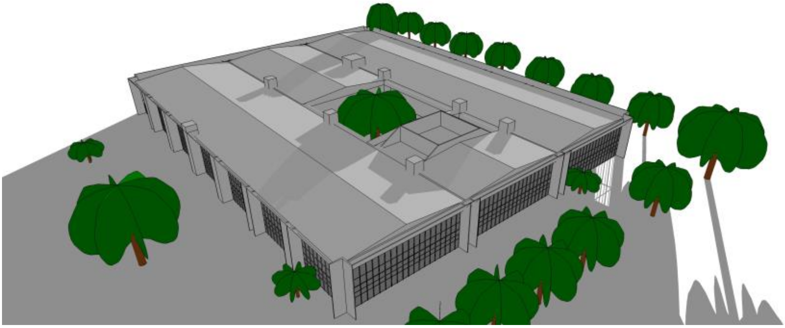


Figure 33 – Building 02’s E surface shadings at 3:00 p.m. in December.

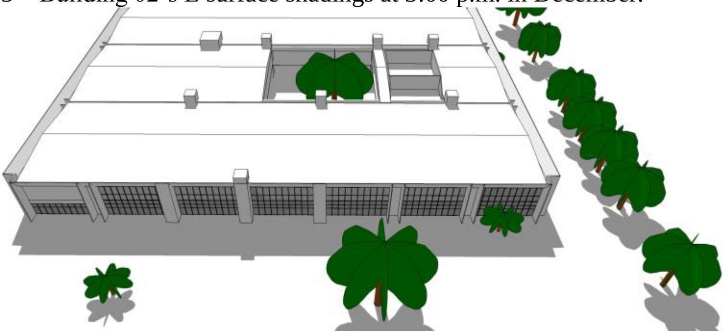
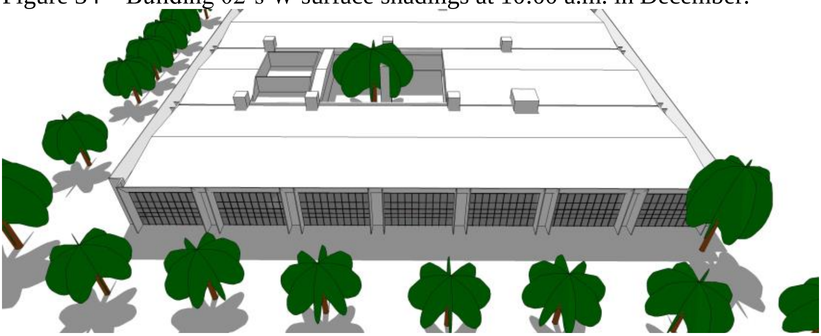


Figure 34 – Building 02’s W surface shadings at 10:00 a.m. in December.



Building 03 was divided in 9 surfaces: 2 rooftops, 3 North surfaces, 2 East surfaces and 2 West surfaces. According to the analysis, both rooftops (annual shading percentages of 0.3% and 5.8%) and one of the

North surfaces (annual shading percentage of 14.2%) were accepted by the shading acceptance criterion.

Building 04 was divided in 4 surfaces: 1 rooftop, 1 North surface, 1 East surface and 1 West surface. The rooftop (annual shading percentage of 1.2%) and the North surface (annual shading percentage of 12.9%) were accepted by the shading acceptance criterion. Figure 35 shows the rooftop's shading mask and Figure 36, North surface's shading mask. It is possible to see that the rooftop is shaded only before 6:00 a.m. and after 6:30 p.m. during almost the entire year; and the North surface is shaded in the morning until 9 a.m. and in the afternoon from 3:00 p.m., in the months of October, November, December, January, February and March, and in the morning until 7:00 a.m. during the months of April, May, June, July, August and September. Some of the most notable shadings are shown in Figures Figure 37 and Figure 38.

Figure 35 – Building 04's rooftop shading mask.

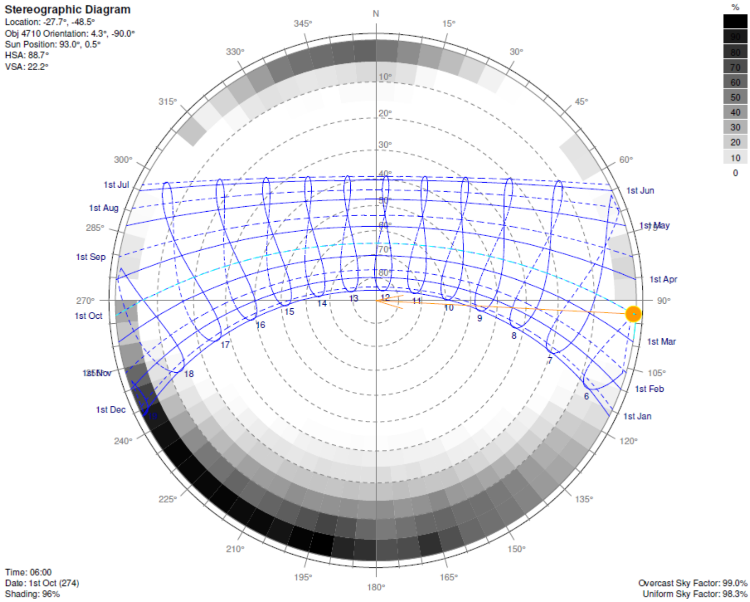


Figure 36 – Building 04’s North surface shading mask.

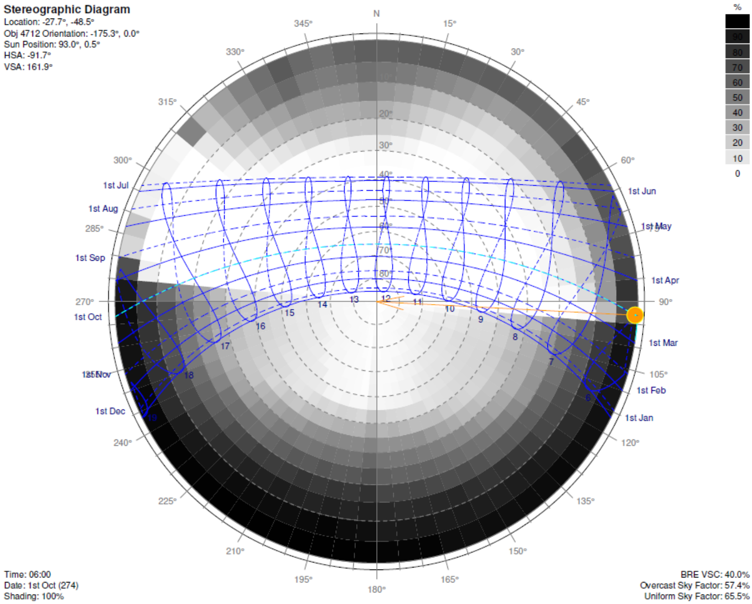


Figure 37 - Building 04’s rooftop and N surface shadings at 6:00 a.m. in October.

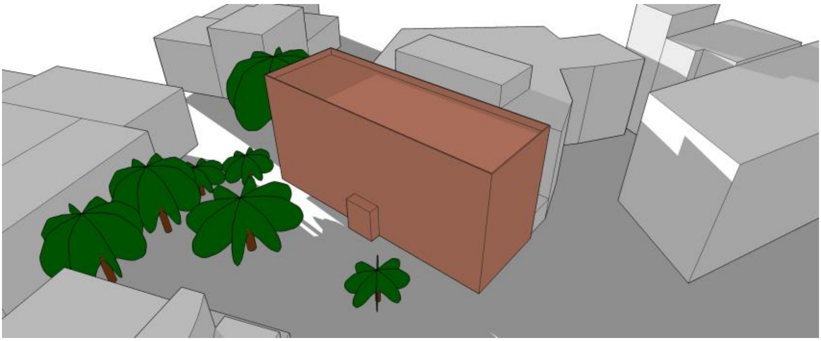
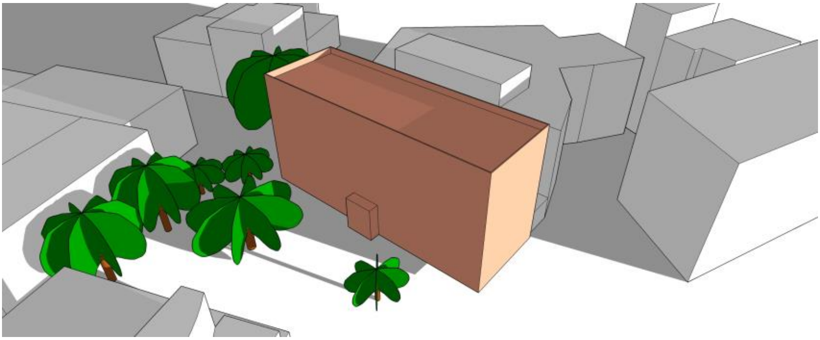


Figure 38 - Building 04’s rooftop and N surface shadings at 6:30 p.m. in October.



Building 05 was divided in 6 surfaces: 1 rooftop, 2 North surfaces, 1 East surface and 2 West surfaces. According to the analysis, the rooftop (annual shading percentage of 9.5%), one of the North surfaces (annual shading percentage of 10.9%), the East surface (annual shading percentage of 17.3%) and both West surfaces (annual shading percentages of 18.2% and 17.6%) were accepted by the shading acceptance criterion.

Building 06 was divided in 4 surfaces: 1 rooftop, 1 North surface, 1 East surface and 1 West surface. According to the analysis, the rooftop (annual shading percentage of 7.2%), the North surface (annual shading percentage of 8.4%) and the East surface (annual shading percentage of 13.7%) were accepted by the shading acceptance criterion.

Building 07 was divided in 12 surfaces for its shading analysis: 1 rooftop, 5 North surfaces, 3 East surfaces and 3 West surfaces. Only the rooftop (annual shading percentage of 3.8%) was accepted by the shading acceptance criterion. Figure 39 shows the rooftop’s shading mask. It is possible to see that the rooftop is shaded only until 7:00 a.m. in the months of April, May, June, July, August and September. Some of the most notable shadings are shown in Figures Figure 40 and Figure 41.

Figure 39 – Building 07's rooftop shading mask.

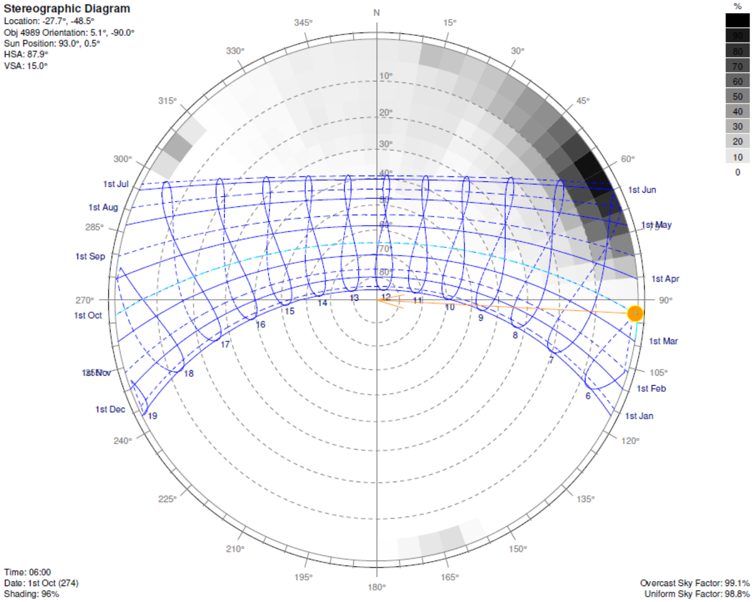


Figure 40 - Building 07's rooftop shadings at 7:00 a.m. in April.

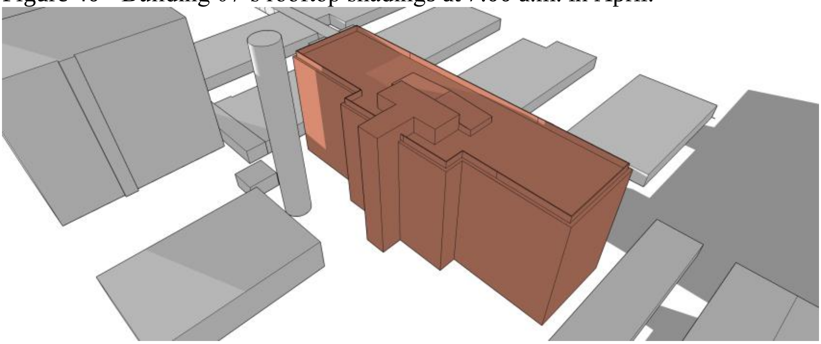
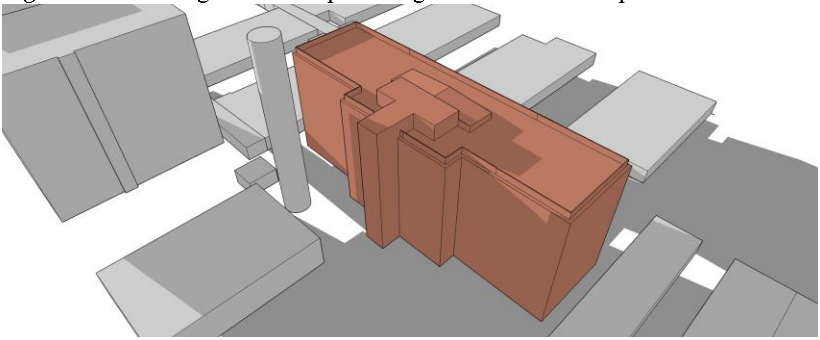
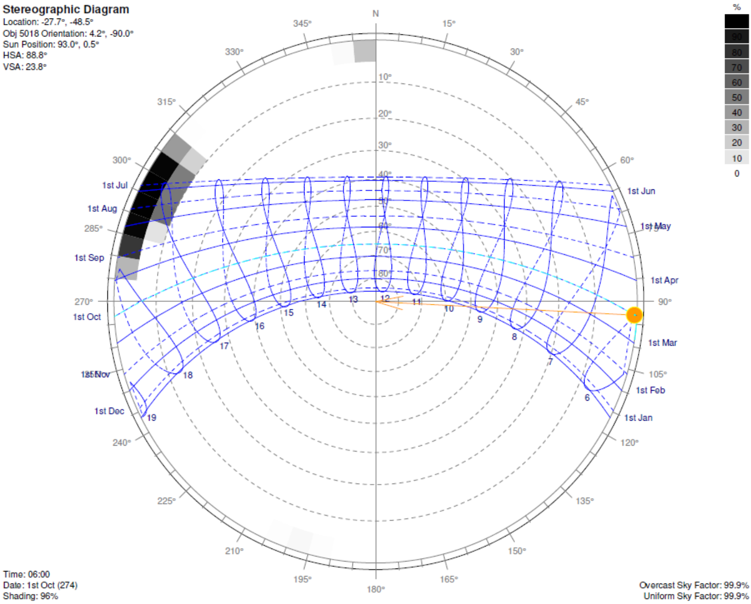


Figure 41 - Building 07’s rooftop shadings at 7:00 a.m. in September.



Building 08 was divided in 11 surfaces: 2 rooftops, 3 North surfaces, 3 East surfaces and 3 West surfaces. Both rooftops (annual shading percentages of 2.3% and 6.1%), one of the East surfaces (annual shading percentage of 13.3%) and one of the West surfaces (annual shading percentage of 15%) were accepted by the shading acceptance criterion. Figure 42 shows the rooftops’ shading masks, Figure 43, East surface’s shading mask, and Figure 44, West surface’s shading mask. It is possible to see that the rooftop is shaded a little bit in the mornings (until approximately 9:00 a.m.) and then only after 6:30 p.m., during the months of April, May, June, July, August and September; the East surface is shaded in the afternoon (starting at 12:00 p.m.) during the whole year; and the West surface is shaded in the morning (until 12:00 p.m.) during all year and from 6:30 p.m. in the months of April, May, June, July, August and September. Some of the most notable shadings are shown in Figures Figure 45 and Figure 46.

Figure 42 – Building 08’s rooftops shading masks.



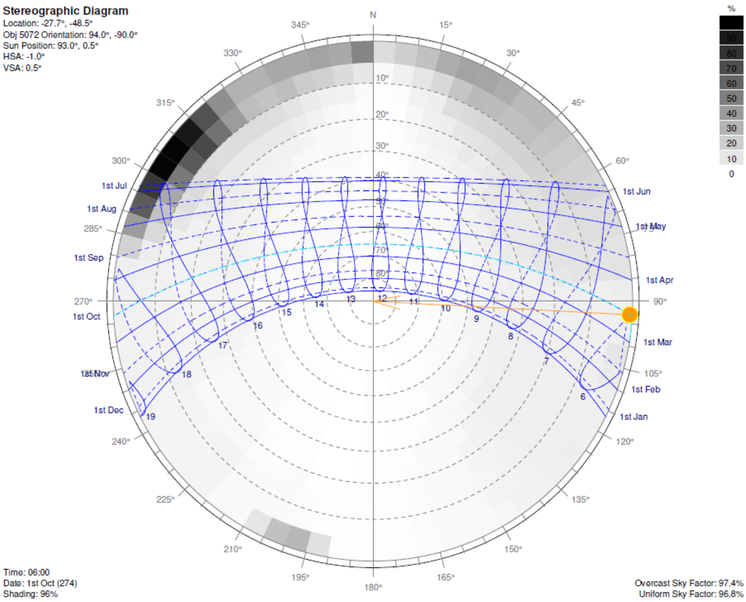


Figure 43 – Building 08’s East surface shading mask.

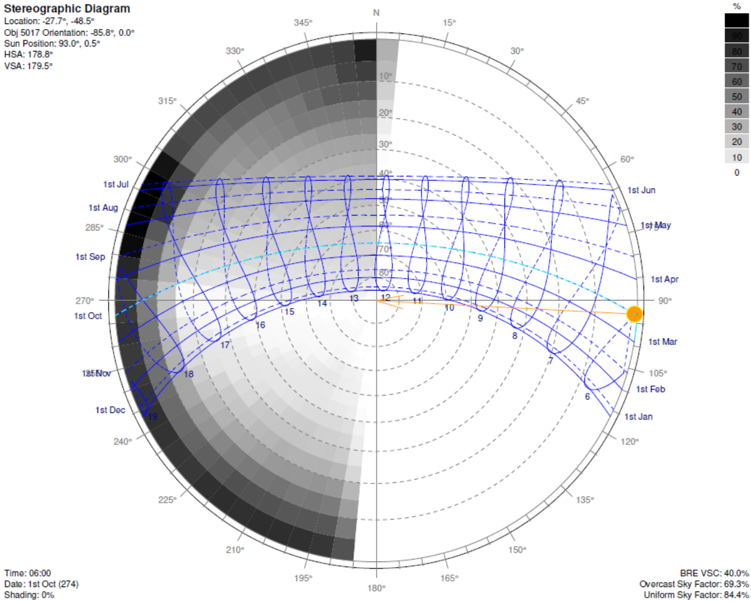


Figure 44 – Building 08’s West surface shading mask.

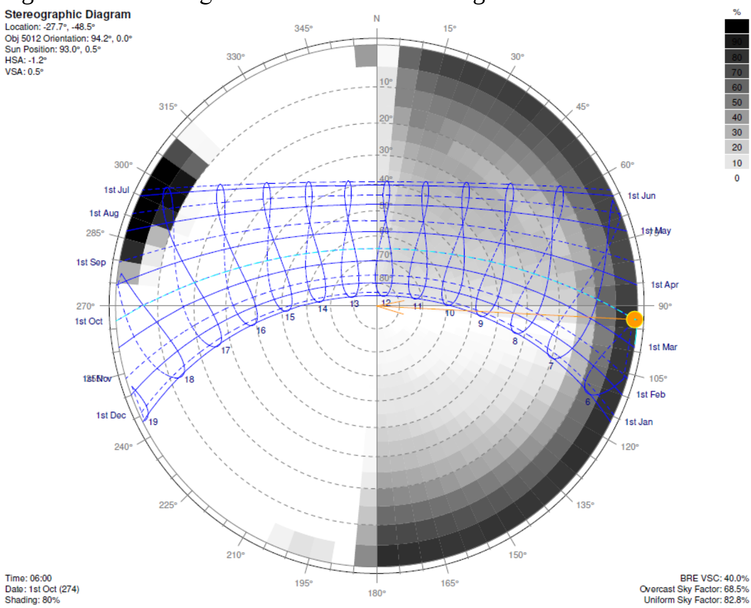


Figure 45 – Building 08’s rooftop and W surface shadings at 9:00 a.m. in May.

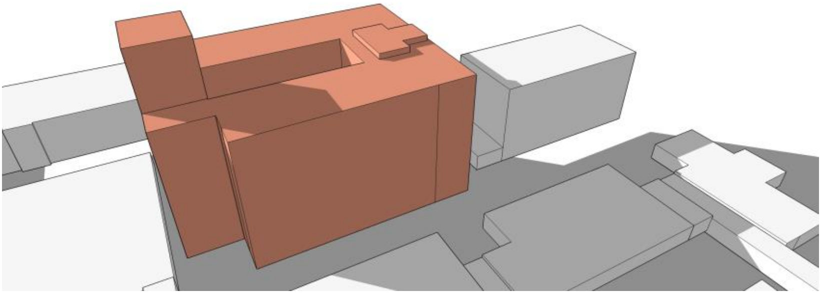
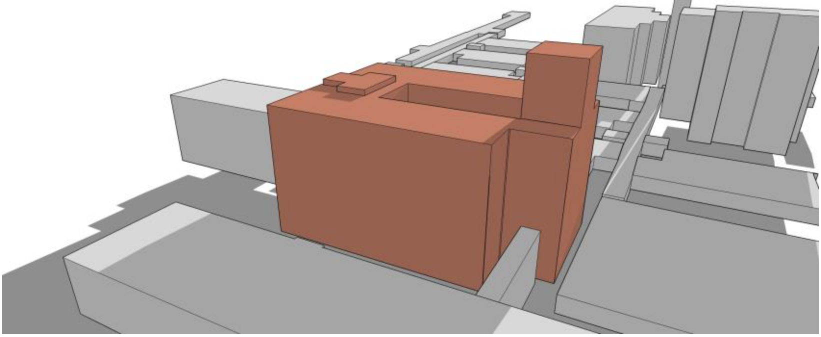


Figure 46 - Building 08’s E surface shadings at 6:30 p.m. in September.



Building 09 was divided in 8 surfaces: 2 rooftops, 2 North surfaces, 2 East surfaces and 2 West surfaces. According to the analysis, one of the rooftops (annual shading percentage of 0.3%) and one of the North surfaces (annual shading percentage of 14.7%) were accepted by the shading acceptance criterion.

Building 10 was divided in 9 surfaces: 1 rooftop, 1 North surface, 1 East surface and 6 West surfaces. The rooftop (annual shading percentage of 7.1%), the North surface (annual shading percentage of 8.1%), the East surface (annual shading percentage of 12.4%) and one of the West surfaces (annual shading percentage of 13.7%) were accepted by the shading acceptance criterion.

Building 11 was divided in 8 surfaces: 2 rooftops, 2 North surfaces, 2 East surfaces and 2 West surfaces. According to the analysis, one of the rooftops (annual shading percentage of 2.4%), both North surfaces (annual shading percentages of 6.3% and 11.3%), the East surface (annual shading percentage of 10.6%) and both West surfaces (annual shading percentage of 11.3% and 9.8%) were accepted by the shading acceptance criterion.

Building 12 was divided in 5 surfaces: 1 rooftop, 2 North surfaces, 1 East surface and 1 West surface. The rooftop (annual shading percentage of 5.8%), one of the North surfaces (annual shading percentage of 9.7%), the East surface (annual shading percentage of 15.9%) and the West surface (annual shading percentage of 12.8%) were accepted by the shading acceptance criterion.

Building 13 was divided in 5 surfaces for its shading analysis: 1 rooftop, 1 North surface, 1 East surface and 2 West surfaces. The rooftop (annual shading percentage of 1.4%), the North surface (annual shading percentage of 5.3%), the East surface (annual shading percentage of 12.8%) and one of the West surfaces (annual shading percentage of 13.2%) were accepted by the shading acceptance criterion.

Building 14 was divided in 11 surfaces: 3 rooftops, 3 North surfaces, 2 East surfaces and 3 West surfaces. According to the analysis, one of the rooftops (annual shading percentage of 0%), one of the North surfaces (annual shading percentage of 10.1%) and one of the West surfaces (annual shading percentage of 11.6%) were accepted by the shading acceptance criterion. Figure 47 shows the rooftop's shading mask, Figure 48, North surface's shading mask, and Figure 49, West surface's shading mask. It is possible to see that the rooftop is never shaded; the North surface is shaded until 8 a.m. during the months of November, December, January, February and March, from 6:30 a.m. to 7:30 a.m. in the months of April, May, June, July, August and September, from 10:30 a.m. to 12:00 p.m. during the whole year, and in the afternoon (from 5:00 p.m.) during the months of April, May, June, July, August, Septermber and October; and the west surface is shaded in the morning (until 12:00 p.m.) during all year. Some of the most notable shadings are shown in Figure 50.

Figure 47 – Building 14’s rooftop shading mask.

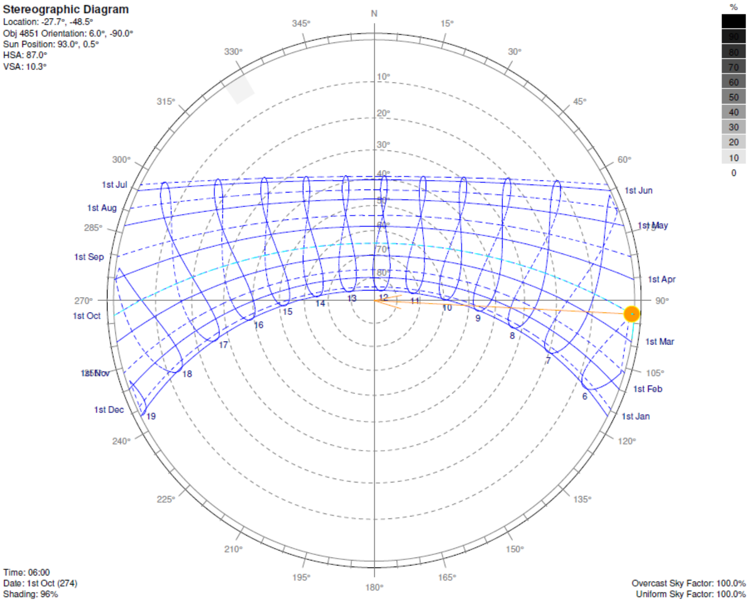


Figure 48 – Building 14’s North surface shading mask.

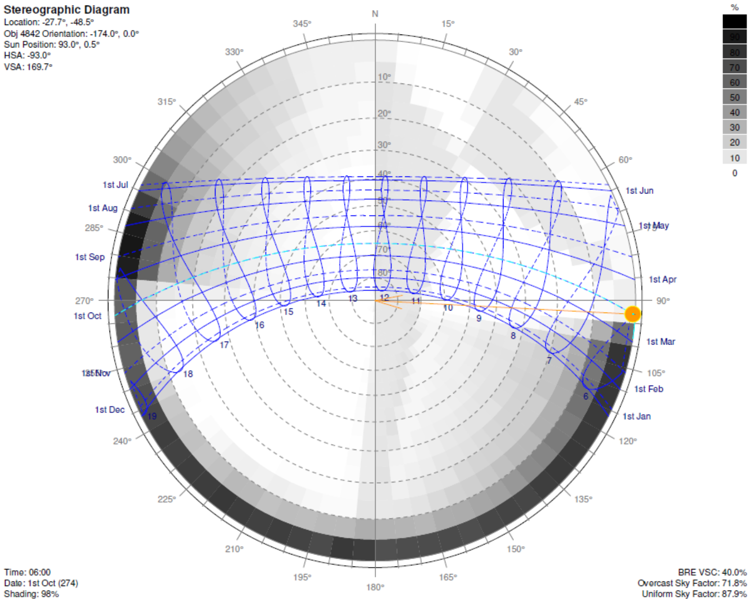


Figure 49 – Building 14’s West surface shading mask.

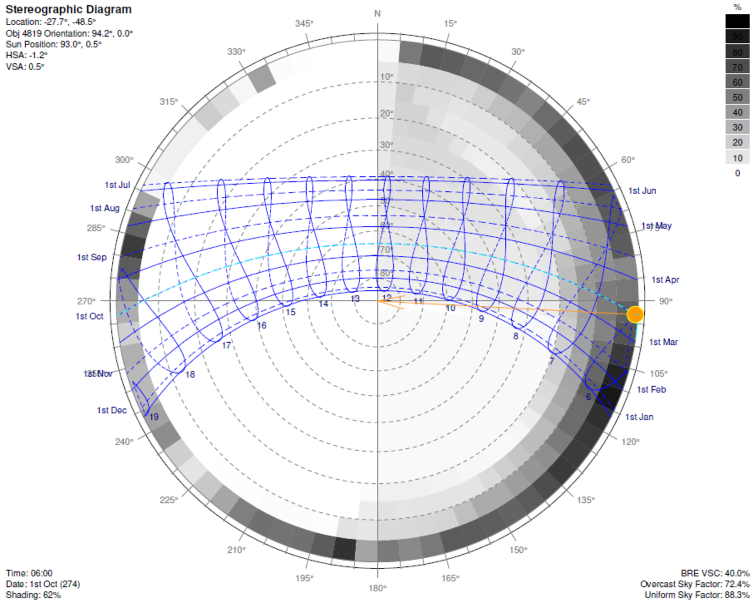
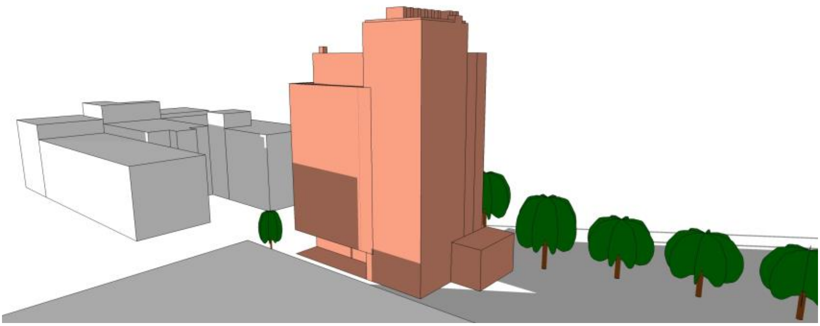


Figure 50 - Building 14’s N and W surfaces shadings at 7:00 a.m. in June.



Building 15 was divided in 8 surfaces: 1 rooftop, 2 North surfaces, 2 East surfaces and 3 West surfaces. According to the analysis, the rooftop (annual shading percentage of 2.5%), one of the North surfaces (annual shading percentage of 13.9%) and one of the West surfaces (annual shading percentage of 16.3%) were accepted by the shading acceptance criterion.

Building 16 was divided in 13 surfaces: 1 rooftop, 4 North surfaces, 3 East surfaces and 5 West surfaces. The rooftop (annual shading percentage of 0%), 2 of the North surfaces (annual shading percentages of 15.7% and 15.6%), one of the East surfaces (annual shading percentage of 16.1%) and one of the West surfaces (annual shading percentage of 14.7%) were accepted by the shading acceptance criterion.

Building 17 was divided in 4 surfaces: 1 rooftop, 1 North surface, 1 East surface and 1 West surface. All of the surfaces were accepted by the shading acceptance criterion. The rooftop had an annual shading percentage of 4.1%, the North surface of 8.1%, the East surface of 11.4% and the West surface of 12%.

Building 18 was divided in 15 surfaces for its shading analysis: 3 rooftops, 2 North surfaces, 5 East surfaces and 5 West surfaces. One of the rooftops (annual shading percentage of 1.1%), both North surfaces (annual shading percentages of 7.9% and 15.1%), 2 East surfaces (annual shading percentages of 13.4% and 9.7%) and one of the West surfaces (annual shading percentage of 12.9%) were accepted by the shading acceptance criterion.

Building 19 was divided in 11 surfaces: 3 rooftops, 3 North surfaces, 3 East surfaces and 2 West surfaces. According to the analysis, one of the rooftops (annual shading percentage of 8.2%) and one of the North surfaces (annual shading percentage of 15.3%) were accepted by the shading acceptance criterion.

Building 20 was divided in 4 surfaces: 1 rooftop, 1 North surface, 1 East surface and 1 West surface. According to the analysis, all the surfaces were accepted by the shading acceptance criterion. The rooftop had an annual shading percentage of 3.8%, the North surface of 9.8%, the East surface of 9.6% and the West surface of 11.2%. Figure 51 shows the rooftop's shading mask, Figure 52, North surface's shading mask, Figure 53, East surface's shading mask, and Figure 54, West surface's shading mask. It is possible to see that the rooftop is shaded only before 6:00 a.m. and after 6:00 p.m. during the whole year; the North surface is shaded in the morning until 9 a.m. and in the afternoon from 3:00 p.m., in the months of September, October, November, December, January, February and March; the East surface is shaded in the afternoon (starting at 12:00 p.m.) during the whole year; and the West surface is shaded in the morning (until 12:00 p.m.) and in the afternoon (starting at 5:30 p.m.) during all year. Some of the most notable shadings are shown in Figures Figure 55, Figure 56 and Figure 57.

Figure 51 – Building 20's rooftop shading mask.

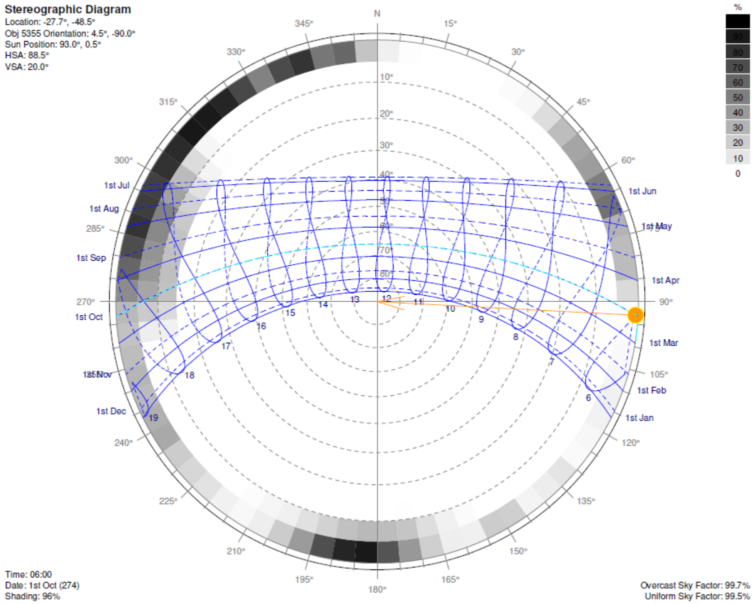


Figure 52 – Building 20's North surface shading mask.

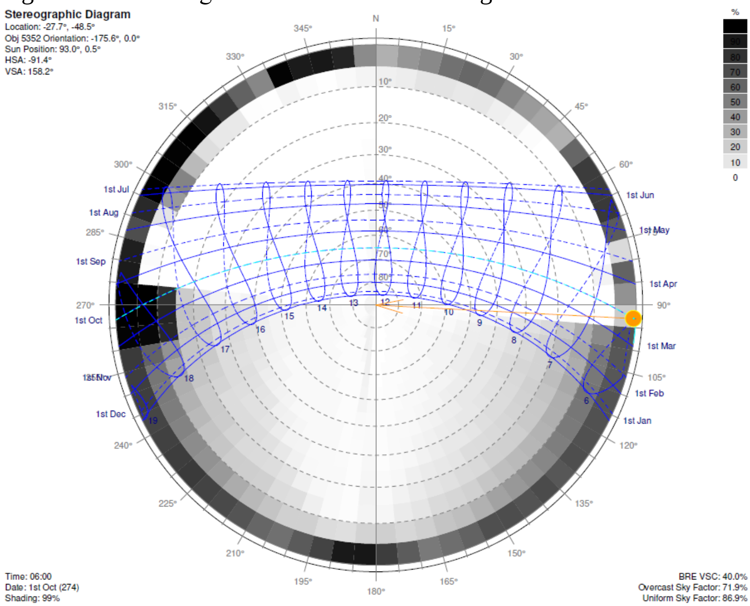


Figure 53 – Building 20’s East surface shading mask.

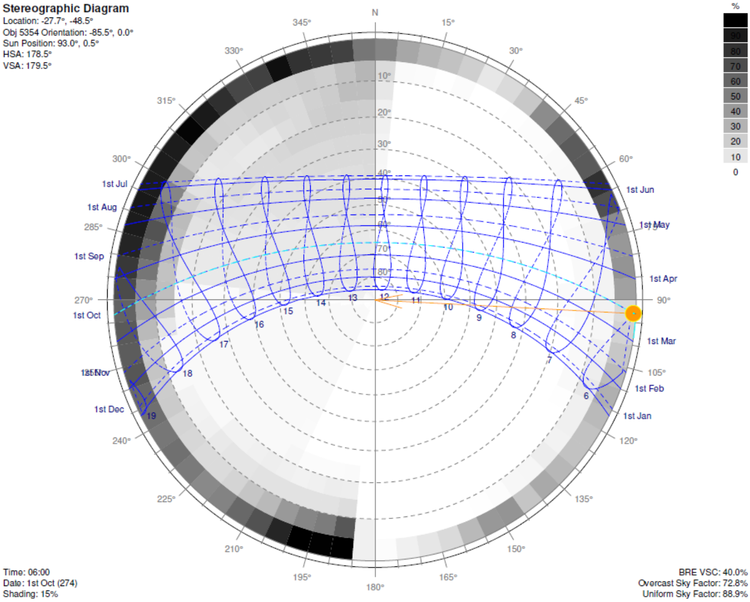


Figure 54 – Building 20’s West surface shading mask.

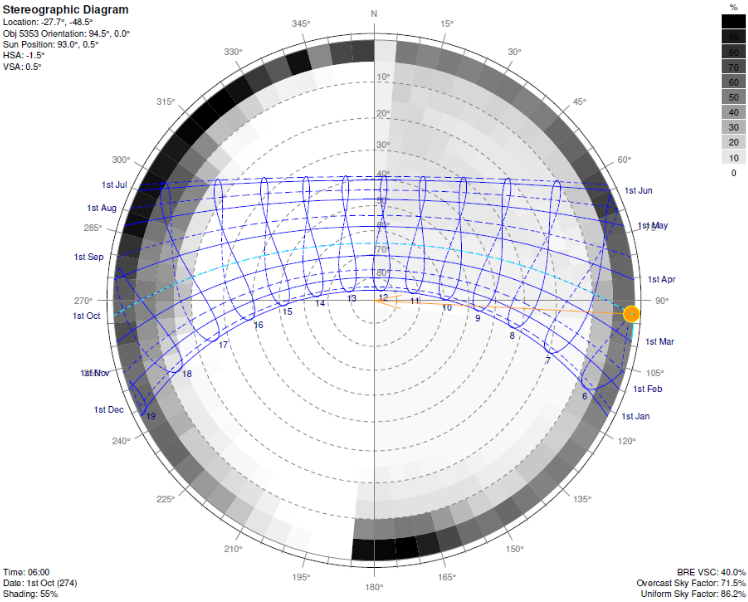


Figure 55 - Building 20's rooftop shadings at 6:00 p.m. in June.

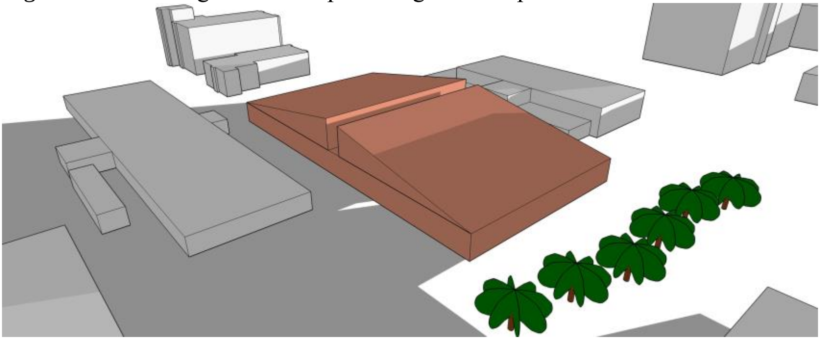


Figure 56 - Building 20's N and E surfaces shadings at 5:00 p.m. in September.

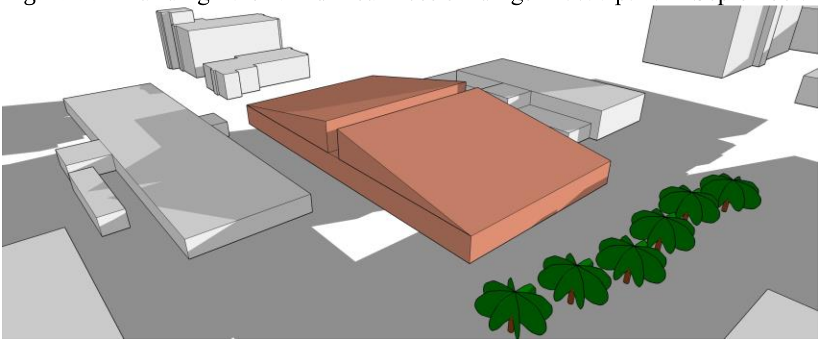
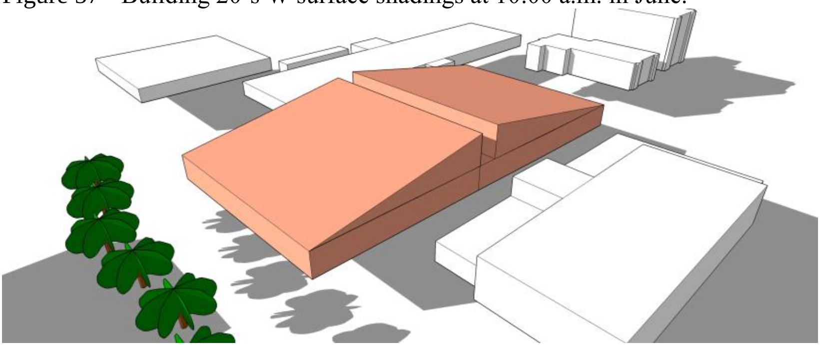


Figure 57 - Building 20's W surface shadings at 10:00 a.m. in June.



Building 21 was divided in 6 surfaces: 1 rooftop, 1 North surface, 2 East surfaces and 2 West surfaces. According to the analysis, all the surfaces were accepted by the shading acceptance criterion. The rooftop had an annual shading percentage of 6.4%, the North surface of 11.6%, the East surfaces of 13.2% and 12.9%, and the West surfaces of 16.9% and 11.9%.

Building 22 was divided in 4 surfaces for its shading analysis: 1 rooftop, 1 North surface, 1 East surface and 1 West surface. According to the analysis, all the surfaces were accepted by the shading acceptance criterion. The rooftop had an annual shading percentage of 4.5%, the North surface of 7.1%, the East surface of 10.9%, and the West surface of 9%.

Building 23 was divided in 11 surfaces: 1 rooftop, 4 North surfaces, 2 East surfaces and 4 West surfaces. The rooftop (annual shading percentage of 3.7%), 2 of the North surfaces (annual shading percentages of 14.3% and 16%), both East surfaces (annual shading percentages of 9% and 11.7%) and 3 of the West surfaces (annual shading percentages of 17.6%, 13.4% and 15.7%) were accepted by the shading acceptance criterion.

Building 24 was divided in 14 surfaces for its shading analysis: 1 rooftop, 3 North surfaces, 4 East surfaces and 6 West surfaces. The rooftop (annual shading percentage of 1.8%), one of the North surfaces (annual shading percentage of 14.8%), one of the East surfaces (annual shading percentage of 16%) and 2 of the West surfaces (annual shading percentages of 4.9% and 7%) were accepted by the shading acceptance criterion.

Building 25 was divided in 17 surfaces: 2 rooftops, 3 North surfaces, 6 East surfaces and 6 West surfaces. According to the analysis, both rooftops (annual shading percentages of 2.9% and 0%), 2 of the North surfaces (annual shading percentages of 12.2% and 8.4%), one of the East surfaces (annual shading percentage of 15.1%) and 2 of the West surfaces (annual shading percentages of 15% and 15.5%) were accepted by the shading acceptance criterion.

Six buildings were chosen to continue the study, according to the different PV integration possibilities and to the availability of the buildings' projects on the university's Architectural and Engineering Project Department. Table 7 shows the chosen building surfaces and their areas.

Table 7 – Chosen buildings and surfaces.

Building	**Surface**	**Área (m²)**
02	Rooftop	5,843
	N façade	601
	E façade	759
	W façade	759
04	Rooftop	319
	N façade	456
07	Rooftop	1,018
08	Rooftop	1,123
	E façade	1,248
	W façade	1,248
14	Rooftop	631
	N façade	927
	W façade	803
20	Rooftop	2,086
	N façade	133
Total		**17,954**

Building 20’s East and West façades were discarded (even being accepted by the shading criterion) because of the building’s architecture. The installation of PV systems on those façades would change and impact too much their original design.

Since the chosen PV module has an area of 1.93 m² and a nominal capacity of 320 Wp, the total area of 17,954 m² should be more than enough to reach an installed capacity of 1 MWp.

To simplify the comprehension of the technical proposals and economic analysis, the buildings were renamed as shown in Table 8.

Table 8 – Buildings' new name and description.

Building	**New name**	**Description**	**Picture**
02	Building A	University's main library	
04	Building B	Sanitary and Environmental Engineering Department's building	
07	Building C	Classroom building	
08	Building D	Communication and Expression Center's building	

Building	New name	Description	Picture
14	Building E	Mechanical Engineering Department's building	
20	Building F	University's restaurant	

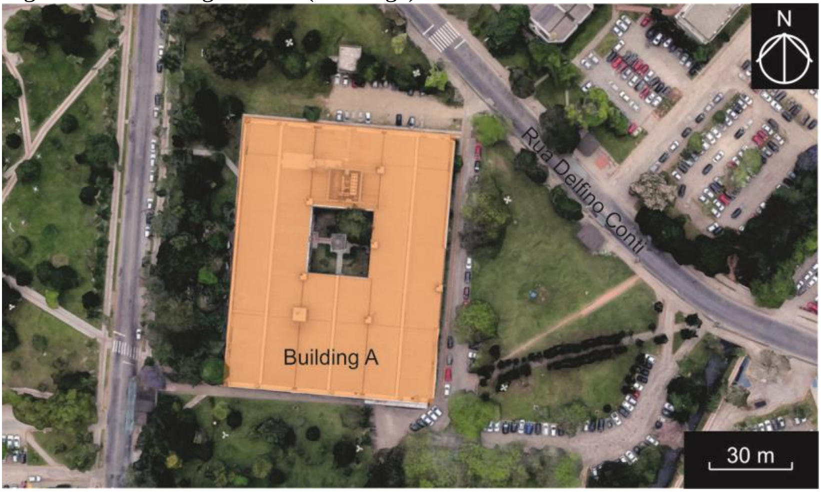
4.2 BUILDING A

Building A is the university's main library, which is located at Rua Eng. Agrônomico Andrei Cristian Ferreira. It was built in 1976 with characteristics of the Brazilian modernist architecture. Since it is a historic building, it is important to remember that any interference proposal must be discussed with its author or analyzed according to its architectural concept. Figure 58 shows the building's site (in orange).

The building's North, East and West façades are composed mainly by large windows with transparent glass. The rooftop is composed of sloped metallic roof tiles. The façades' area corresponds to about 0.36 times the rooftop area.

The PV system was suggested in the shape of *brise soleil* on the three façades, and on the rooftop the PV system followed the roof tile's tilt and orientation.

Figure 58 – Building A’s site (in orange).

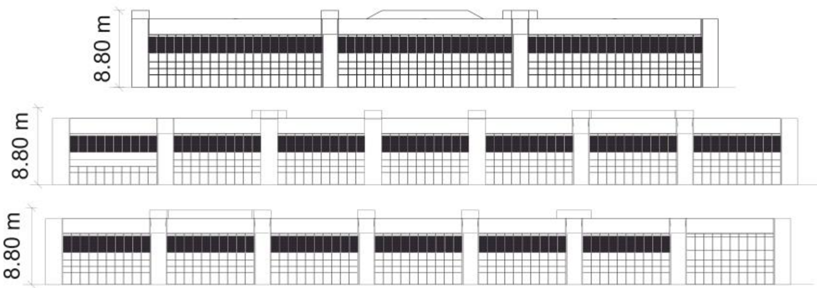


Source: Adapted from Google Earth.

4.2.1 Technical feasibility

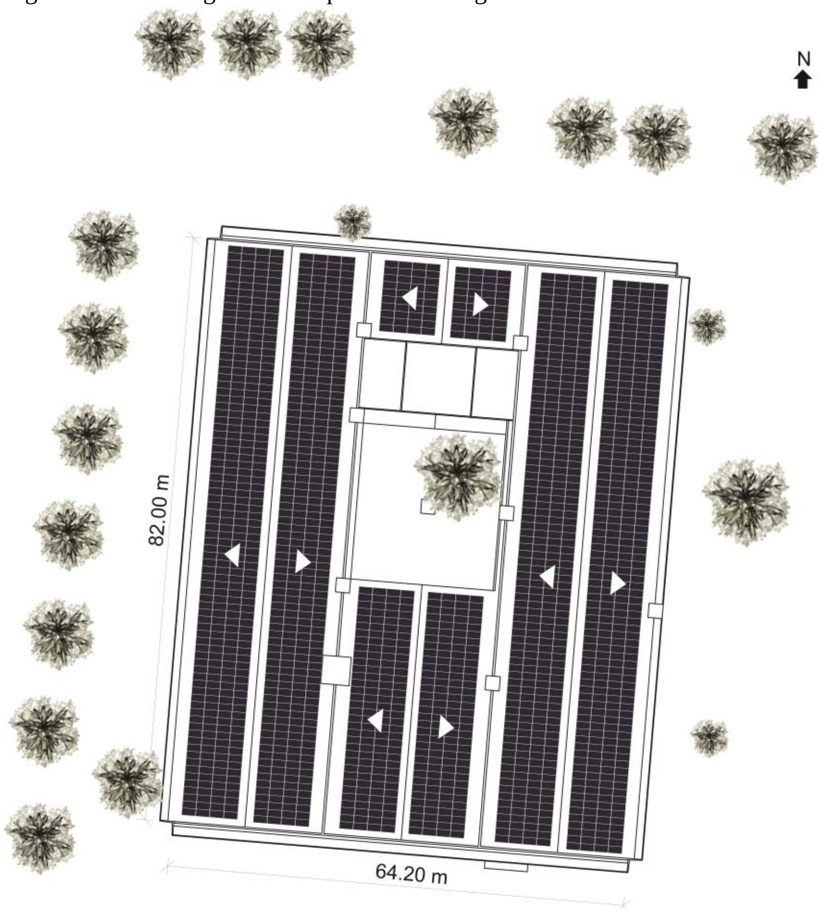
Brise soleil composed by 190 mc-Si PV modules were proposed to building A’s façades, as shown in Figure 59, in order to improve the building’s internal thermal and visual comfort. Since the building is a library where students spend time reading and doing their work, direct sunlight is not welcome. The suggested PV *brise soleil* will contribute to decrease the direct sunlight that enters the building, which will also result in reducing the use of air conditioners, besides generating solar electricity.

Figure 59 – Building A’s North, East and West façades, respectively, with PV integration.



The rooftop integration is composed of 1,628 PV modules and is shown in Figure 60. The system follows the roof tile's tilt and orientation.

Figure 60 – Building A's rooftop with PV integration.



The simulation results for North, East and West façades, and for the rooftop, generated by PVsyst, can be found in Appendix A.

Shading losses calculated using PVsyst on the North façade were of 13.9%/year, on the East façade of 9.6%/year, on the West façade of 17.3%/year and on the rooftop of 1.1%/year. All systems have, therefore, acceptable shading losses.

The most significant losses on the façades' systems were due to the incidence of irradiation on the modules in relation to the global horizontal irradiation (40.0%/year, 45.9%/year and 43.4%/year for North, East and West façades, respectively). These losses occurred because the systems are being installed on façades, that is, with PV modules tilted at 90°. The most significant loss of the rooftop system was due to the temperature of the modules, since they are installed very close to the roof tiles, which results in a loss of 7.8% per year.

The complete PV system's (façades plus rooftop) characteristics are shown in Table 9.

Table 9 – Characteristics of building A's PV integration.

	Azimuth	**Tilt**	**Installed Capacity (kWp)**	**Energy Generation (MWh/year)**	**Yield (kWh/kWp/ year)**
N façade	5°E	90°	19.20	11.85	617
E façade	95°E	90°	22.40	11.84	529
W façade	85°W	90°	19.20	9.33	486
Rooftop	95°E + 85°W	5°	521	615.04	1,181
Total	**-**	**-**	**581.80**	**648.06**	**-**

Since the PV systems have a positive impact on the architecture of the building (by improving its thermal and visual comforts and by following the building's shape on the rooftop), they were accepted in technical terms.

4.2.2 Economic analysis

The building's North façade PV system's economic analysis had zero viable cases. 7 out of the 18 cases would be viable if we only looked at their NPVs, IRRs and DPBTs, therefore they had positive NPVs, IRRs higher than the MARRs established and DPBTs lower than 30 years. However, the LCOEs of all 18 cases were higher than \$0.08388/kWh (R\$0.31068/kWh). Case 12 had the best results, with a NPV of \$21,108.18 (R\$78,178.46), an IRR of 7.44%, a DPBT of 21 years and a LCOE of \$0.08746/kWh (R\$0.32391/kWh).

With the addition of East and West façades, there are still zero economic viable cases, with worst results than if only north façade was considered. Again, case 12 had the best results, with a NPV of \$47,162.74

(R$174,676.81), an IRR of 6.32%, a DPBT of 23 years and a LCOE of $0.09936/kWh (R$0.36801/kWh).

With the addition of a PV system to the building's rooftop, the economic analysis has improved. All of the 18 economic cases have become viable, so the PV systems were also accepted in economic terms. The best one, case 12, has a NPV of $2,083,603.19 (R$7,717,048.86), an IRR of 15.93%, a DPBT of 9 years and a LCOE of $0.03917/kWh (R$0.14509/kWh).

For the 18 economic cases, Figure 61 shows the values of NPV, Figure 62 values of IRR, Figure 63 values of DPBT and Figure 64, values of LCOE, for building A's North façade, all façades (North, East and West), and all façades plus rooftops. When, for a certain case, the NPV bars are not appearing on the graphs, it is because their values are very close to zero (according to the graphs' scale).

Figure 61 – NPV for building A's 18 economic cases.

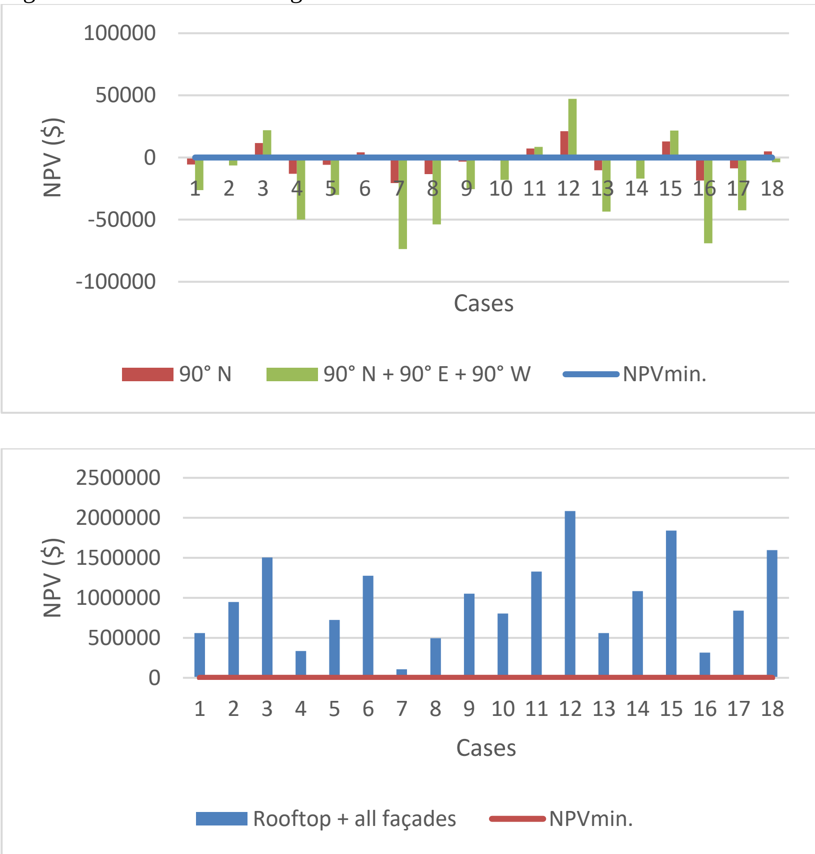


Figure 62 – IRR for building A’s 18 economic cases.

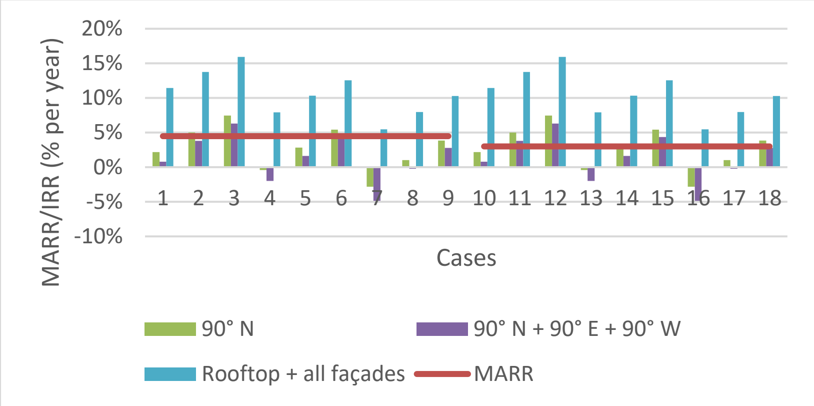


Figure 63 – DPBT for building A’s 18 economic cases.

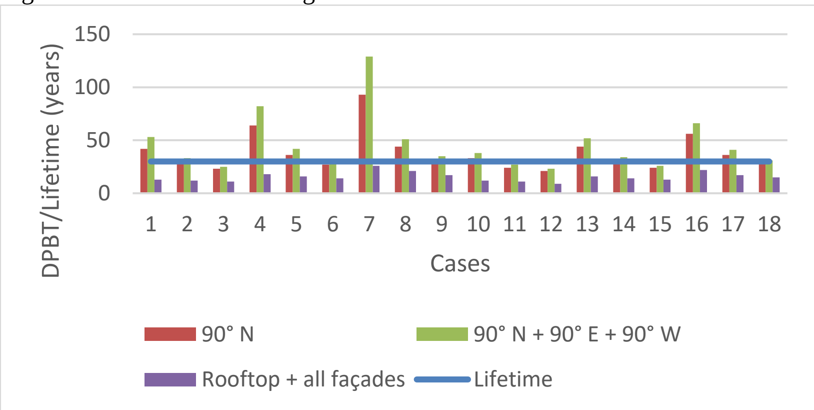
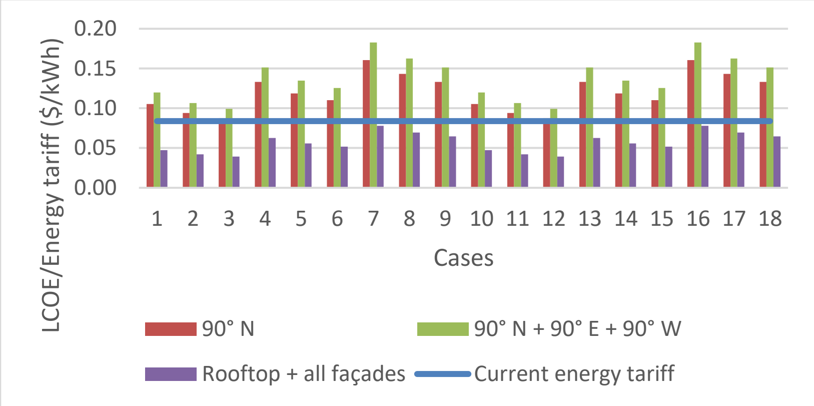


Figure 64 – LCOE for building A’s 18 economic cases.



4.3 BUILDING B

Building B is one of the Sanitary and Environmental Engineering Department’s buildings, which is located close to Rua Delfino Conti. Figure 65 shows the building’s site (in orange).

The building’s North façade is composed mainly of brick walls and by windows with transparent glass, horizontally distributed through the façade. The rooftop is composed of inclined metallic roof tiles. The façade’s area corresponds to about 1.43 times the rooftop area.

The PV system was suggested in the shape of *brise soleil* on the North façade, and on the rooftop the PV system followed the roof tile’s tilt and orientation.

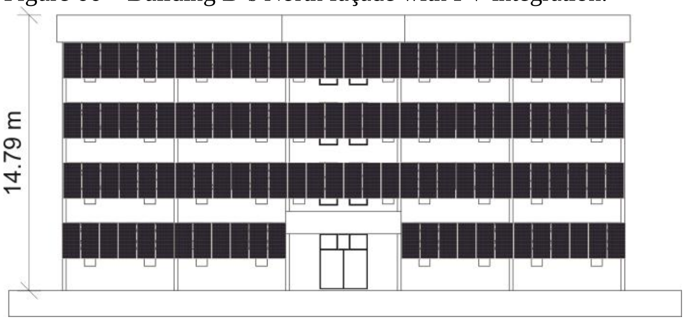
Figure 65 – Building B’s site (in orange).

Source: Adapted from Google Earth.

4.3.1 Technical feasibility

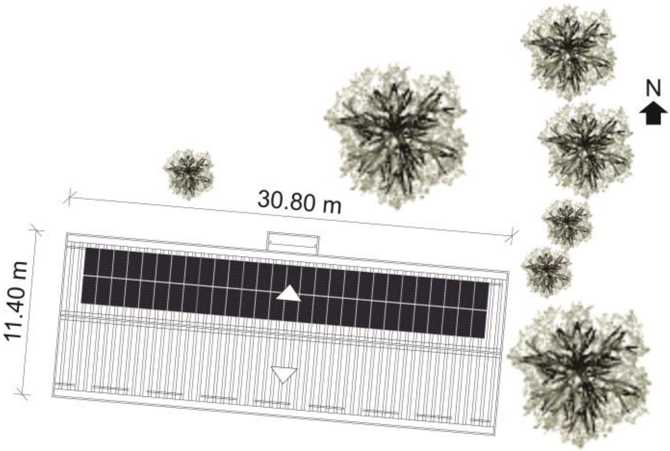
Brise soleil composed by 114 mc-Si PV modules were proposed to building B’s North façade, as shown in Figure 66, in order to improve the building’s internal thermal and visual comforts.

Figure 66 – Building B’s North façade with PV integration.



The rooftop integration is composed by 56 PV modules and is shown in Figure 67. The system follows the roof tile’s tilt and orientation.

Figure 67 – Building B’s rooftop with PV integration.



Simulation results for the North façade and for the rooftop, generated by PVsyst, can be found in Appendix B.

Shading losses, calculated by PVsyst, were of 15.5%/year on the North façade and of 0.2%/year on the rooftop. All systems, then, have acceptable shading losses.

The most significant loss of the façade’s system was due to the incidence of irradiation on the modules in relation to the global horizontal irradiation (40.0%/year). This loss occurred because the system is being installed on a façade, that is, with PV modules tilted at 90°. The most significant loss of the rooftop system was due to the temperature of the modules, since they are installed very close to the roof tiles, which results in a loss of 7.9% per year.

The complete PV system’s (façade plus rooftop) characteristics are shown in Table 10.

Table 10 – Characteristics of building B’s PV integration.

	Azimuth	**Tilt**	**Installed Capacity (kWp)**	**Energy Generation (MWh/year)**	**Yield (kWh/kWp/ year)**
N façade	5°E	90°	36.50	20.84	571
Rooftop	5°E	5°	17.92	21.96	1,225
Total	**-**	**-**	**54.42**	**42.80**	**-**

Since the PV systems have a positive impact on the architecture of the building (by improving its thermal and visual comforts and by following the building's shape on the rooftop), they were accepted in technical terms.

4.3.2 Economic analysis

The building's North façade PV system's economic analysis had zero viable cases. 6 out of the 18 cases would be viable if we only looked at their NPVs, IRRs and DPBTs, therefore they had positive NPVs, IRRs higher than the MARRs established and DPBTs lower than 30 years. However, the LCOEs of all 18 cases were higher than $0.08388/kWh (R$0.31068/kWh). Case 12 had the best results, with a NPV of $32,823.66 (R$121,569.10), an IRR of 6.76%, a DPBT of 22 years and a LCOE of $0.09444/kWh (R$0.34976/kWh).

With the addition of a PV system to the building's rooftop, the economic analysis has improved. There are now 8 viable economic cases, so the PV systems were also accepted in economic terms. The best one, case 12, has a NPV of $106,387.88 (R$394,029.18), an IRR of 10.41%, a DPBT of 15 years and a LCOE of $0.06375/kWh (R$0.23612/kWh).

For the 18 economic cases, Figure 68 shows the values of NPV, Figure 69 values of IRR, Figure 70 values of DPBT and Figure 71 values of LCOE, for building B's North façade, and North façade plus rooftop. When, for a certain case, the NPV bar is not appearing on the graph, it is because it has a value very close to zero (according to the graph's scale).

Figure 68 – NPV for building B's 18 economic cases.

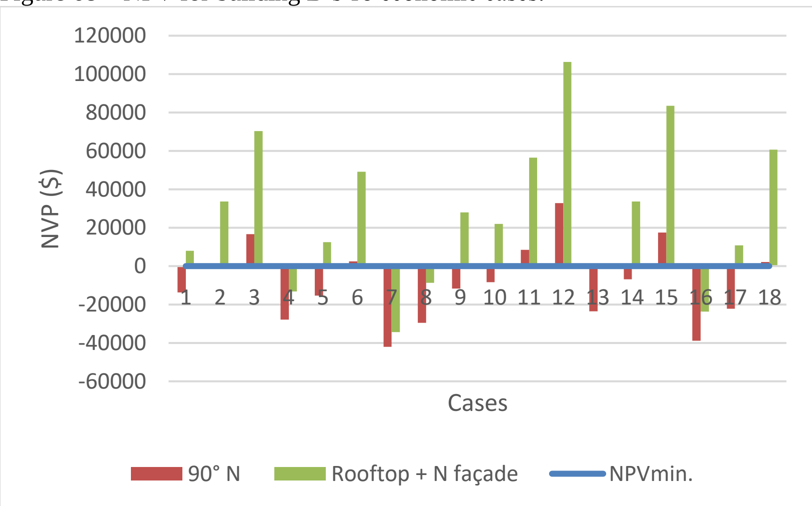


Figure 69 – IRR for building B's 18 economic cases.

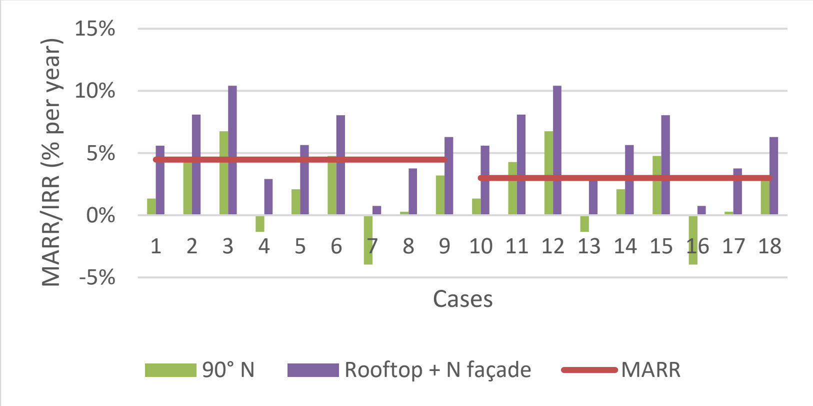


Figure 70 – DPBT for building B's 18 economic cases.

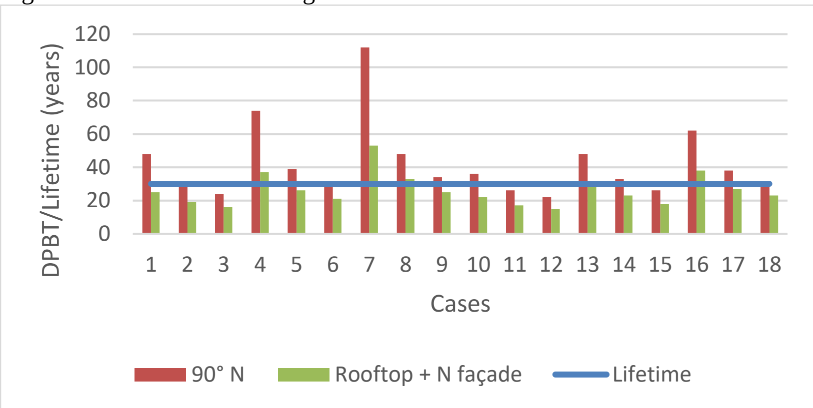
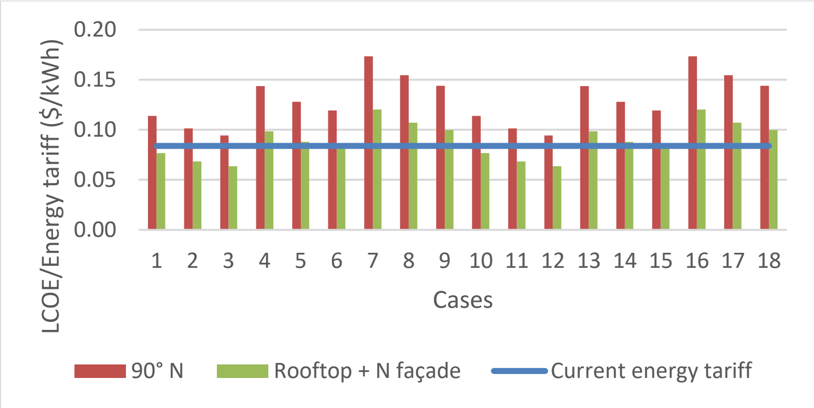


Figure 71 – LCOE for building B's 18 economic cases.



4.4 BUILDING C

Building C is a classroom building that is located close to Rua Eng. Agronômico Andrei Cristian Ferreira. Figure 72 shows the building's site (in orange).

The building's rooftop is composed of inclined metallic roof tiles and a glass cover that allows the building to use sunlight for illumination. The PV modules were integrated only to the metallic roof tiles area.

The PV system was suggested only on the rooftop, following the roof tiles' tilt and orientation.

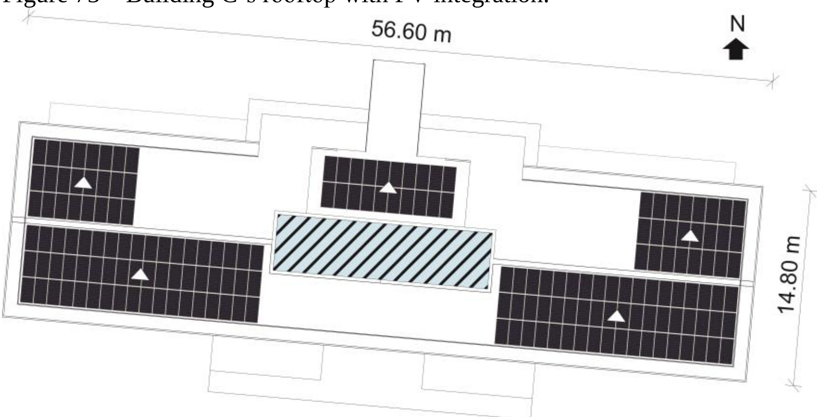
Figure 72 – Building C’s site (in orange).

Source: Adapted from Google Earth.

4.4.1 Technical feasibility

The rooftop integration is composed of 176 PV modules and is shown in Figure 73. The system follows the roof tiles’ tilt and orientation.

Figure 73 – Building C’s rooftop with PV integration.



The simulation report for the rooftop, generated by PVsyst, can be found in Appendix C.

Shading losses were of 3.9%/year. The system, then, has acceptable shading losses.

The most significant loss was due to the temperature of the modules, since they are installed very close to the roof tiles, resulting in a loss of 8.0% per year.

The PV system's (rooftop) characteristics are shown in Table 11.

Table 11 – Characteristics of building C's PV integration.

	Azimuth	**Tilt**	**Installed Capacity (kWp)**	**Energy Generation (MWh/year)**	**Yield (kWh/kWp/ year)**
Rooftop	6°E	10°	56.30	67.90	1,206
Total	**-**	**-**	**56.30**	**67.90**	**-**

Since the PV system has a positive impact on the architecture of the building (by following the building's shape), it was accepted in technical terms.

4.4.2 Economic analysis

The building's rooftop PV system economic analysis showed that all 18 economic cases were viable. Case 12 had the best results, with a NPV of $226,307.64 (R$838,176.45), an IRR of 17.38%, a DPBT of 8 years and a LCOE of $0.03519/kWh (R$0.13036/kWh).

For the 18 economic cases, Figure 74 shows the values of NPV, Figure 75 values of IRR, Figure 76 values of DPBT and Figure 77 values of LCOE, for building C's rooftop.

Figure 74 – NPV for building C's 18 economic cases.

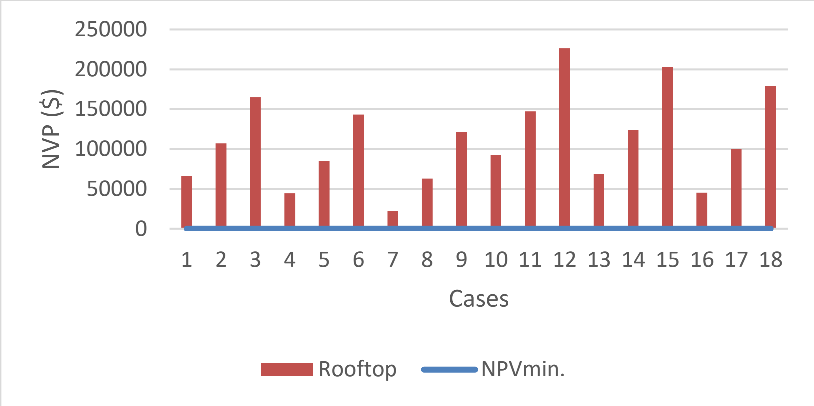


Figure 75 – IRR for building C's 18 economic cases.

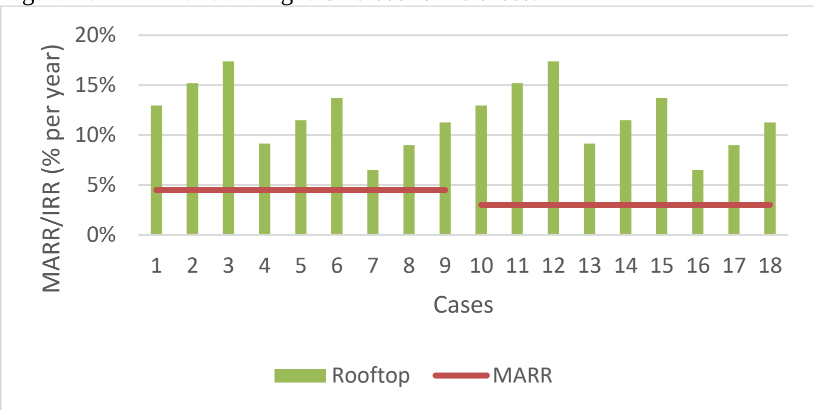


Figure 76 – DPBT for building C's 18 economic cases.

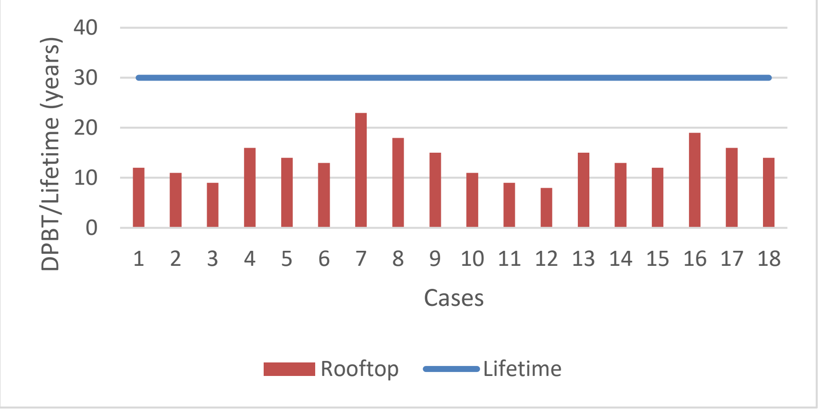
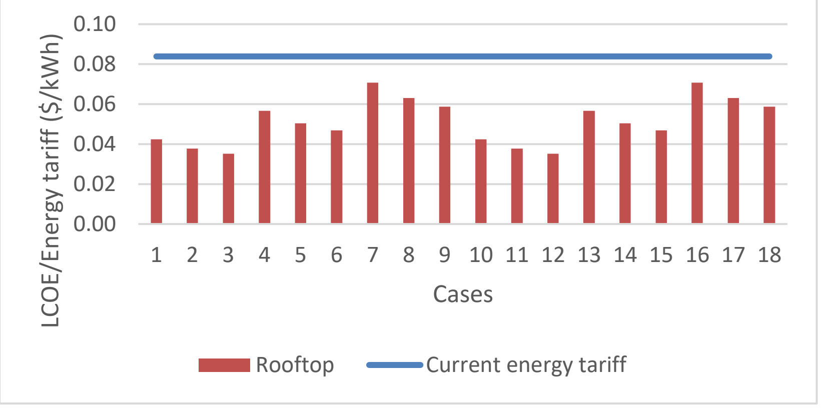


Figure 77 – LCOE for building C's 18 economic cases.



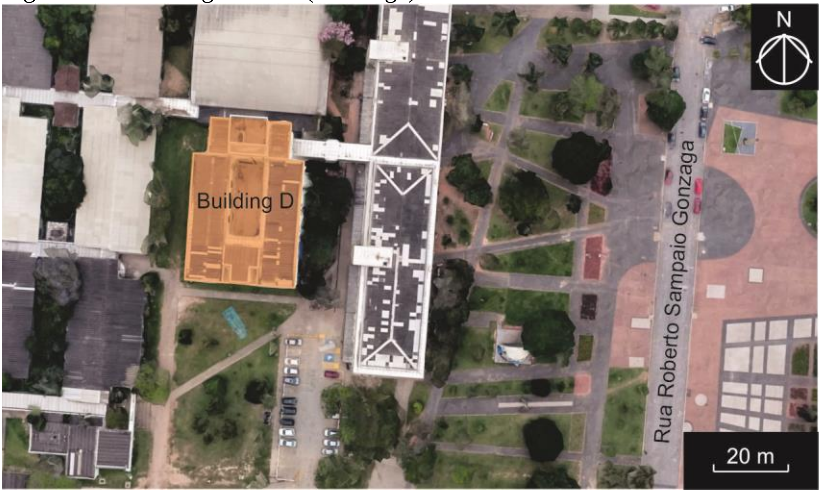
4.5 BUILDING D

Building D is one of the Communication and Expression Center's buildings, which is located close to Rua Roberto Sampaio Gonzaga. Figure 78 shows the building's site (in orange).

The building's East and West façades are composed mainly of brick walls and windows with transparent glass. The rooftop is composed of inclined metallic roof tiles. The façades' area correspond to about 2.22 times the rooftop area.

The PV system was suggested in the shape of double-skin façades on the East and West façades, and on the rooftop the PV system followed the roof tile's tilt and orientation.

Figure 78 – Building D's site (in orange).

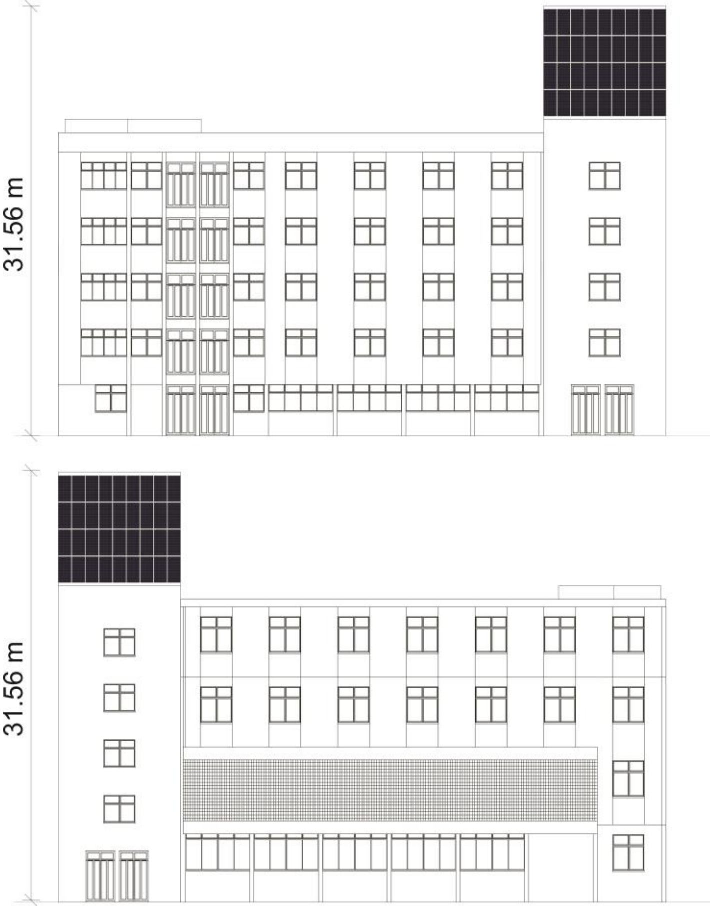


Source: Adapted from Google Earth.

4.5.1 Technical feasibility

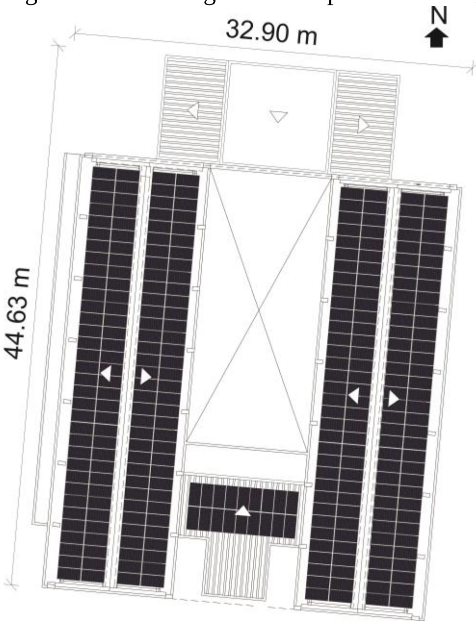
Double-skin façades composed by 36 mc-Si PV modules each, were proposed to building D's East and West façades, as shown in Figure 79. The objective was to create a contrast between the façades' parts and give more quality to its architecture.

Figure 79 – Building D’s East and West façades, respectively, with PV integration.



The rooftop integration is composed by 290 PV modules and is shown in Figure 80. The system follows the roof tile’s tilt and orientation.

Figure 80 – Building D's rooftop with PV integration.



The simulation reports for East and West façades and for the rooftop, generated by PVsyst, can be found in Appendix D.

Shading losses on East façade were of 0.4%/year, on West façade of 3.6%/year and on the rooftop of 2.9%/year. All systems, then, have acceptable shading losses.

The most significant loss of the façades' systems was due to the incidence of irradiation on the modules in relation to the global horizontal irradiation (45.8%/year and 43.5%/year for east and west façades, respectively). This loss occurred because the systems are being installed on façades, that is, with PV modules tilted at 90°. The most significant loss of the rooftop system was due to the temperature of the modules, since they are installed very close to the roof tiles, resulting in a loss of 7.7% per year.

The complete PV system's (façades plus rooftop) characteristics are shown in Table 12.

Table 12 – Characteristics of building D's PV integration.

	Azimuth	Tilt	Installed Capacity (kWp)	Energy Generation (MWh/year)	Yield (kWh/kWp/year)
E façade	94°E	90°	11.52	7.53	653
W façade	86°W	90°	11.52	7.51	652
Rooftop	94°E + 4°E + 86°W	5°	92.80	110.89	1,195
Total	**-**	**-**	**115.84**	**125.93**	**-**

Since the PV systems have a positive influence on the architecture of the building (by improving its thermal comfort and its façades' design, and by following the building's shape on the rooftop), the PV systems were accepted in technical terms.

4.5.2 Economic analysis

The building's East and West façades PV systems' economic analysis, together, had 2 viable cases. 8 out of the 18 cases would be viable if we only looked at their NPVs, IRRs and DPBTs, therefore they had positive NPVs, IRRs higher than the MARRs established and DPBTs lower than 30 years. However, the LCOEs of 16 cases were higher than \$0.08388/kWh (R\$0.31068/kWh). Case 12 had the best results, with a NPV of \$28,923.82 (R\$107,125.25), an IRR of 7.95%, a DPBT of 19 years and a LCOE of \$0.08268/kWh (R\$0.30623/kWh).

With the addition of a PV system to the building's rooftop, the economic analysis has improved. Now, all 18 economic cases are viable, so the PV systems were accepted in economic terms. The best one, case 12, has a NPV of \$397,506.92 (R\$1,472,247.86), an IRR of 15.31%, a DPBT of 11 years and a LCOE of \$0.04114/kWh (R\$0.15238/kWh).

For the 18 economic cases, Figure 81 shows the values of NPV, Figure 82 values of IRR,

Figure 83 values of DPBT and Figure 84 values of LCOE, for building D's East and West façades, and for both façades plus rooftop. When, for a certain case, the NPV and/or IRR bars are not appearing on the graphs, it is because their values are very close to zero (according to the graphs' scale).

Figure 81 – NPV for building D’s 18 economic cases.

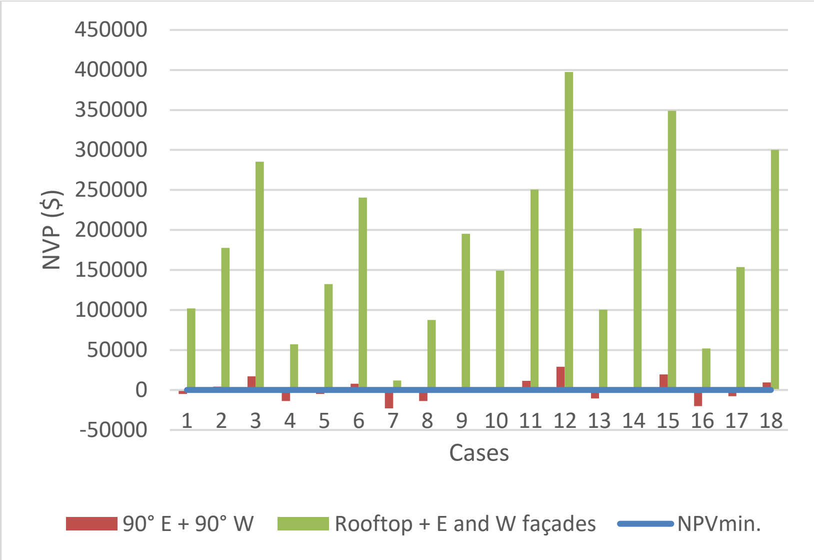


Figure 82 – IRR for building D’s 18 economic cases.

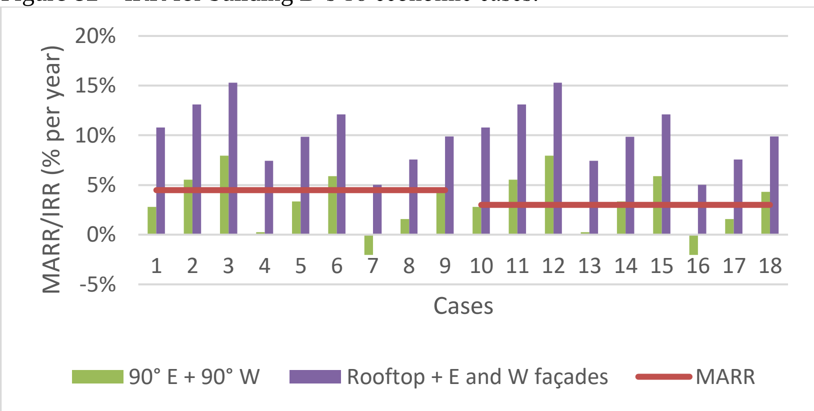


Figure 83 – DPBT for building D's 18 economic cases.

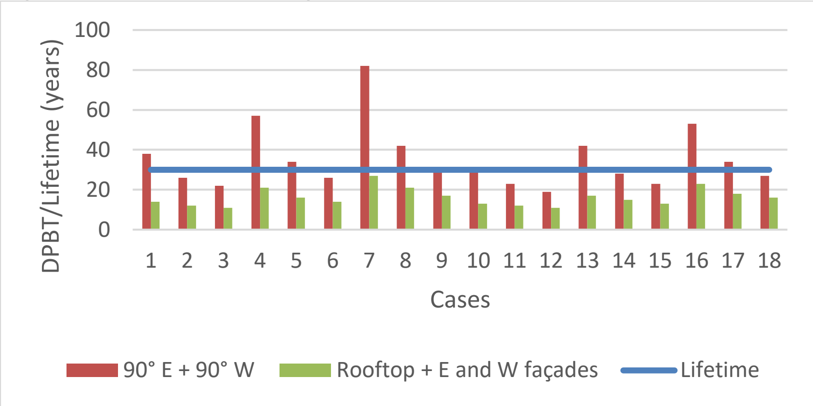
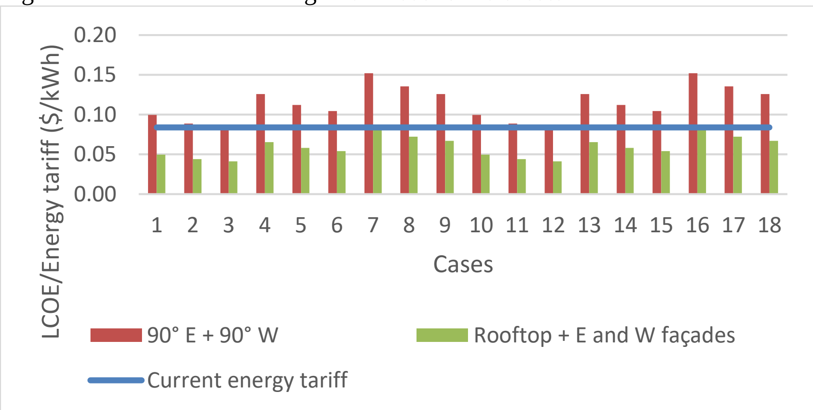


Figure 84 – LCOE for building D's 18 economic cases.



4.6 BUILDING E

Building E is a non-finished construction that belongs to the Mechanical Engineering Department, located at Rua Eng. Agrônomico Andrei Cristian Ferreira, next to one of the university accesses. Figure 85 shows the building's site (in orange).

Aluminum shutters for air circulation, windows with transparent glass and a big tiled blind wall compose building E's North façade. The West façade is composed of a big tiled blind wall and windows with transparent glass. Tiles were considered on the blind walls for this study because many of the university's building have tiled façades, but the blind walls are not installed yet, so it is not known what the walls' coating material will actually be. The rooftop is a plain concrete slab. The areas of the 2 façades represent about 2.74 times the rooftop area.

The PV system was suggested on the shape of double-skin façades on the blind wall areas of the North and West façades, and on the rooftop the PV system didn't follow the building's tilt, only its orientation.

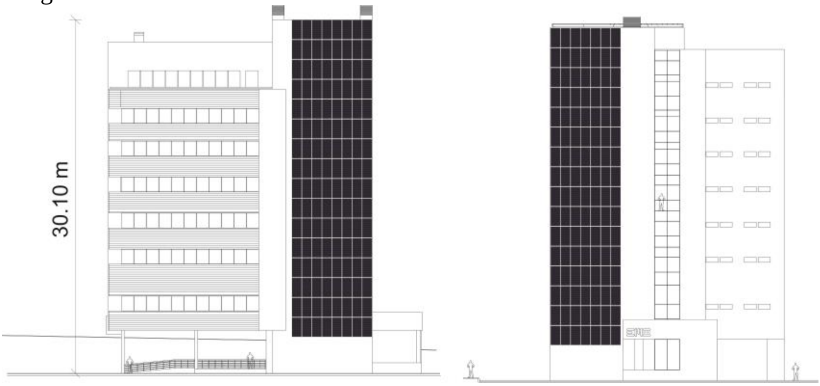
Figure 85 – Building E's implantation (in orange).

Source: Adapted from Google Earth.

4.6.1 Technical feasibility

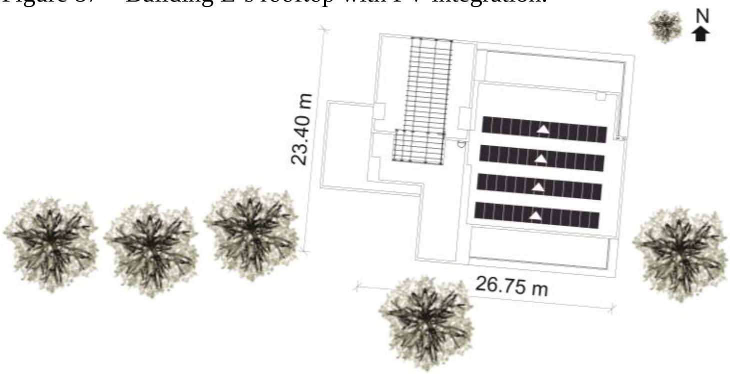
The PV integration suggested for building E's North and West façades is composed of 240 mc-Si PV modules, as the layouts shown in Figure 86. Its purpose, besides generating energy, was to improve the building's thermal comfort and to eliminate the expenditure with the ceramic tiles that would otherwise cover the façades, by the creation of a double-skin façade that substitutes this coating material with PV modules.

Figure 86 – Building E’s North and West façades, respectively, with PV integration.



The rooftop integration is composed of 52 PV modules and is shown in Figure 87. The system follows the building’s orientation, but not it’s tilt, since the building has a plain horizontal rooftop, what is not recommended for the installation of PV systems. The rooftop area was not entirely used due to the existence of terraces and equipment.

Figure 87 – Building E’s rooftop with PV integration.



The simulation reports for North and West façades, and for the rooftop, generated by PVsyst, can be found in Appendix E.

Shading losses on North façade were of 1.3%/year, on West façade of 1.5%/year and on the rooftop of 9.9%/year. All systems, then, have acceptable shading losses.

The most significant losses of the façades' systems were due to the incidence of irradiation on the modules in relation to the global horizontal irradiation (40.0%/year and 43.3%/year for North and West façades, respectively). These losses occurred because the systems are being installed on façades, that is, with PV modules tilted at 90°. The most significant loss of the rooftop system was due to shading, since elements of the building itself, such as the platband and the water tank tower, caused shading over the PV modules.

The complete PV system's (façades plus rooftop) characteristics are shown in Table 13.

Table 13 – Characteristics of building E's PV integration.

	Azimuth	**Tilt**	**Installed Capacity (kWp)**	**Energy Generation (MWh/year)**	**Yield (kWh/kWp/ year)**
N façade	5°E	90°	41.00	28.85	704
W façade	85°W	90°	35.80	23.66	660
Rooftop	5°E	27°	16.64	19.11	1,149
Total	**-**	**-**	**93.44**	**71.62**	**-**

Since the PV systems have a positive impact on the architecture of the building (by improving its thermal comfort and by having a PV system on its rooftop that causes zero impact on its architecture shape), the PV systems were accepted in technical terms.

4.6.2 Economic analysis

Since the façades' coating material was replaced by the PV modules, the cost of the tiles, considered as \$40.5/m² (R\$150/m²) (this was the average value found at a prices survey in the Brazilian market), was subtracted from the initial investment. This brought a significant improvement to the economic viability of the project.

The building's North façade PV system's economic analysis had 8 viable cases. 14 out of the 18 cases would be viable if we only looked at their NPVs, IRRs and DPBTs, therefore they had positive NPVs, IRRs higher than the MARRs established and DPBTs lower than 30 years. However, the LCOEs of 6 of these 14 cases were higher than \$0.08388/kWh (R\$0.31068/kWh). Case 12 had the best results, with a NPV of \$76,282.29 (R\$282,527.45), an IRR of 11.30%, a DPBT of 14 years and a LCOE of \$0.05842/kWh (R\$0.21637/kWh).

With the addition of the West façade, there are still 8 economic viable cases, with worst results than if only north façade was considered. Again, case 12 had the best results, with a NPV of \$136,066.80 (R\$503,951.10), an IRR of 10.99%, a DPBT of 15 years and a LCOE of \$0.06019/kWh (R\$0.22292/kWh).

With the addition of a PV system to building E's rooftop, the economic analysis has improved. There are now 10 economic viable cases. Then, the PV systems were also accepted in economic terms. The best one, case 12, has a NPV of \$199,416.11 (R\$738,578.18), an IRR of 12.20%, a DPBT of 13 years and a LCOE of \$0.05369/kWh (R\$0.19885/kWh).

For the 18 economic cases, Figure 88 shows the values of NPV, Figure 89 values of IRR, Figure 90 values of DPBT and Figure 91 values of LCOE, for building E's North façade, North and East façades, and both façades plus rooftops. When, for a certain case, the NPV bar is not appearing on the graph, it is because it has a value very close to zero (according to the graph's scale).

Figure 88 – NPV for building E's 18 economic cases.

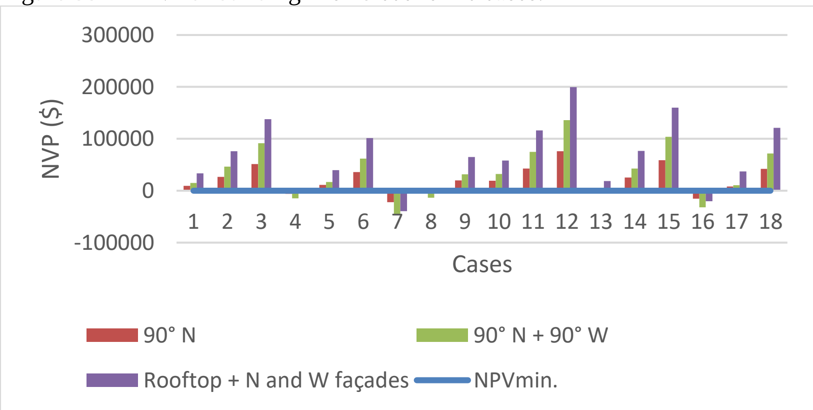


Figure 89 – IRR for building E's 18 economic cases.

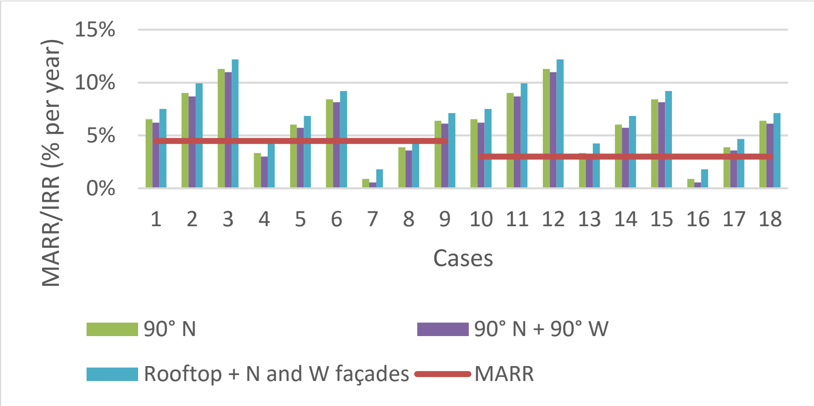


Figure 90 – DPBT for building E's 18 economic cases.

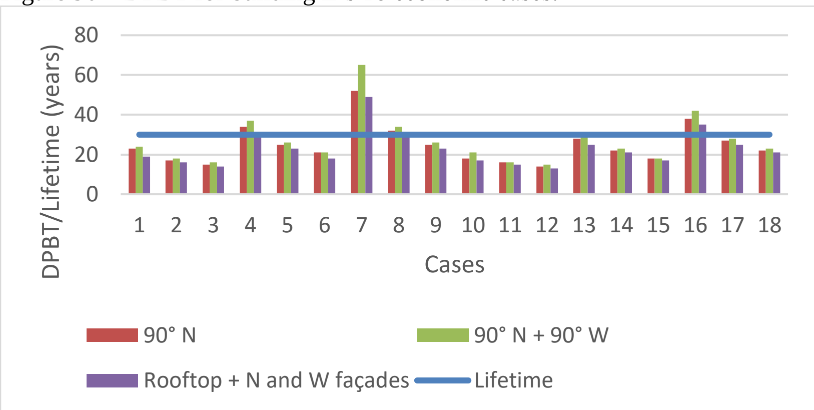
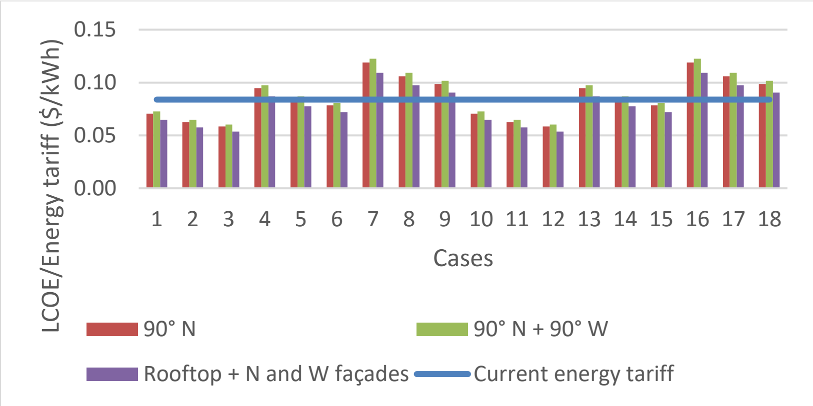


Figure 91 – LCOE for building E's 18 economic cases.



4.7 BUILDING F

Building F is the university's restaurant. Figure 92 shows the building's site (in orange).

The building's North façade is composed mainly of brick walls and by windows with transparent glass. The rooftop is composed of tilted metallic roof tiles. The façade's area corresponds to about 0.06 times the rooftop area.

The PV system was suggested in the shape of *brise soleil* on the North façade, and on the rooftop the PV system followed the roof tile's tilt and orientation.

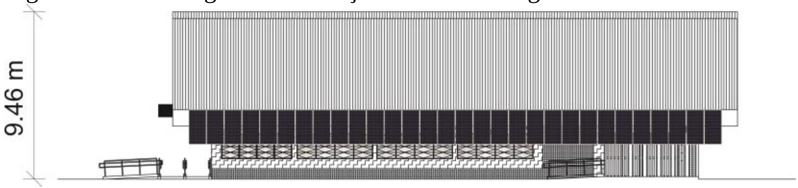
Figure 92 – Building F’s site (in orange).

Source: Adapted from Google Earth.

4.7.1 Technical feasibility

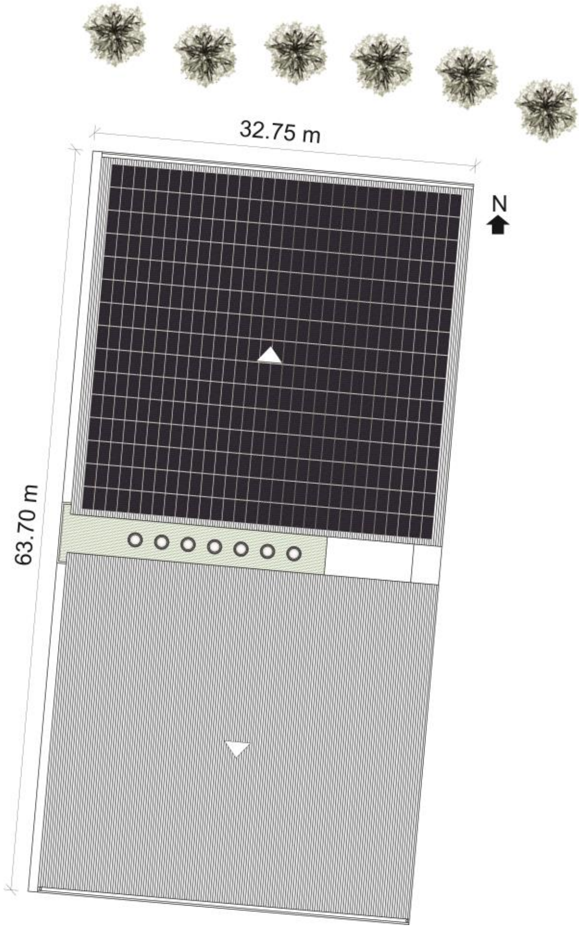
A *Brise soleil* composed of 30 mc-Si PV modules was proposed to building F’s North façade, as shown in Figure 93, in order to improve the building’s internal thermal and visual comforts.

Figure 93 – Building F’s North façade with PV integration.



The rooftop integration is composed by 450 PV modules and is shown in Figure 94. The system follows the roof tile’s tilt and orientation.

Figure 94 – Building F’s rooftop with PV integration.



The simulation reports for the North façade and for the rooftop, generated by PVsyst, can be found in Appendix F.

Shading losses on the north façade were of 17.1%/year and on the rooftop of 0.5%/year. All systems, then, have acceptable shading losses.

The most significant loss of the façade’s system was due to the incidence of irradiation on the modules in relation to the global horizontal irradiation (40.1%/year). This loss occurred because the system is being installed on a façade, that is, with PV modules tilted at 90°. The most significant loss of the rooftop system was due to the temperature of the modules, since they are installed very close to the roof tiles, resulting in a loss of 8.2% per year.

The complete PV system's (façade plus rooftop) characteristics are shown in Table 14.

Table 14 – Characteristics of building F's PV integration.

	Azimuth	**Tilt**	**Installed Capacity (kWp)**	**Energy Generation (MWh/year)**	**Yield (kWh/kWp/ year)**
N façade	4°E	90°	9.60	5.72	596
Rooftop	4°E	10°	144	182.63	1,268
Total	**-**	**-**	**153.60**	**188.35**	**-**

Since the PV systems proposed have a positive impact on the architecture of the building (by improving its thermal and visual comforts and by following the building's shape on the rooftop), the PV systems were accepted in technical terms.

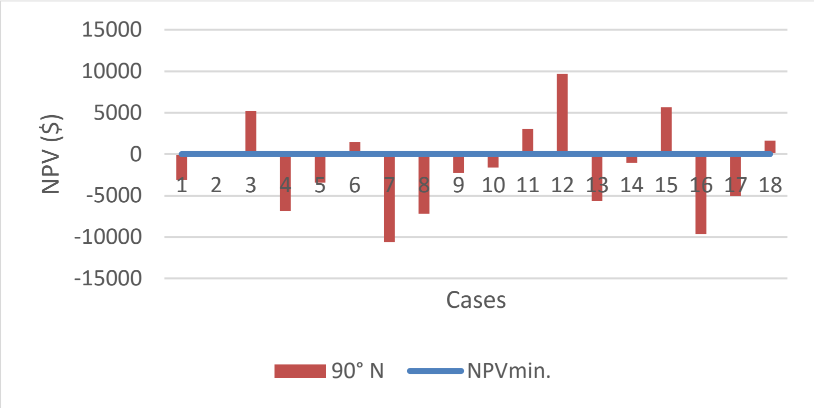
4.7.2 Economic analysis

The building's North façade PV system's economic analysis had zero viable cases. 7 out of the 18 cases would be viable if we only looked at their NPVs, IRRs and DPBTs, therefore they had positive NPVs, IRRs higher than the MARRs established and DPBTs lower than 30 years. However, the LCOEs of all 18 cases were higher than \$0.08388/kWh (R\$0.31068/kWh). Case 12 had the best results, with a NPV of \$9,682.93 (R\$35,862.72), an IRR of 7.14%, a DPBT of 21 years and a LCOE of \$0.09050/kWh (R\$0.33517/kWh).

With the addition of a PV system to the building's rooftop, the economic analysis has improved. Now, all the 18 economic cases are viable. Then, the PV systems were also accepted in economic terms. The best one, case 12, has a NPV of \$627,853.49 (R\$2,325,383.29), an IRR of 17.39%, a DPBT of 8 years and a LCOE of \$0.03519/kWh (R\$0.13034/kWh).

For the 18 economic cases, Figure 95 shows the values of NPV, Figure 96 values of IRR, Figure 97 values of DPBT and Figure 98 values of LCOE, for building F's North façade, and North façade plus rooftop. When, for a certain case, the NPV bar is not appearing on the graph, it is because it has a value very close to zero (according to the graph's scale).

Figure 95 – NPV for building F’s 18 economic cases.



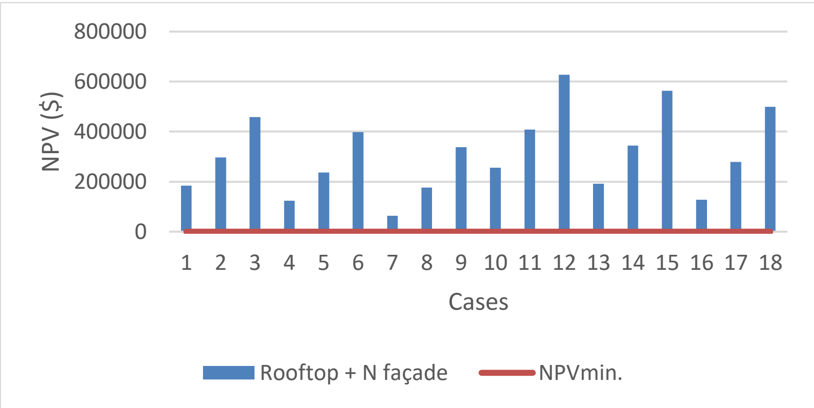


Figure 96 – IRR for building F’s 18 economic cases.

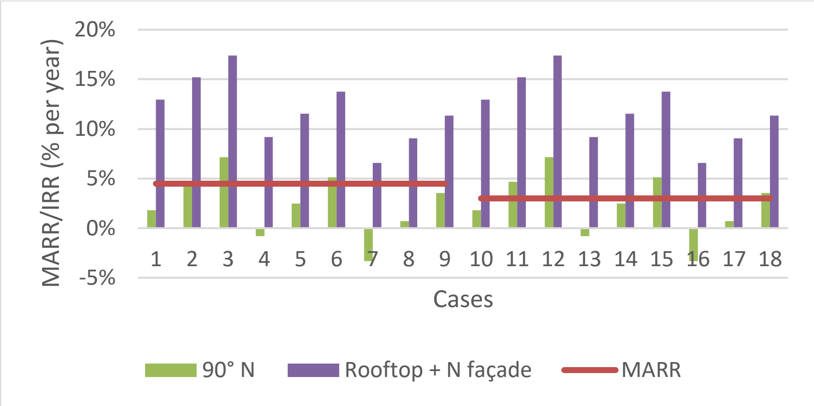


Figure 97 – DPBT for building F’s 18 economic cases.

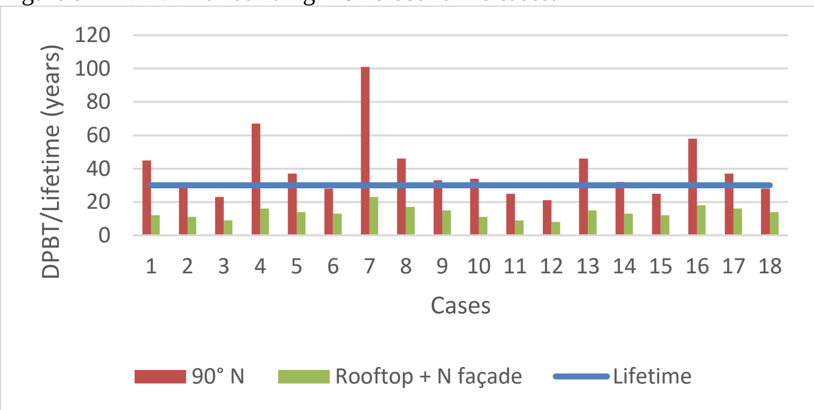
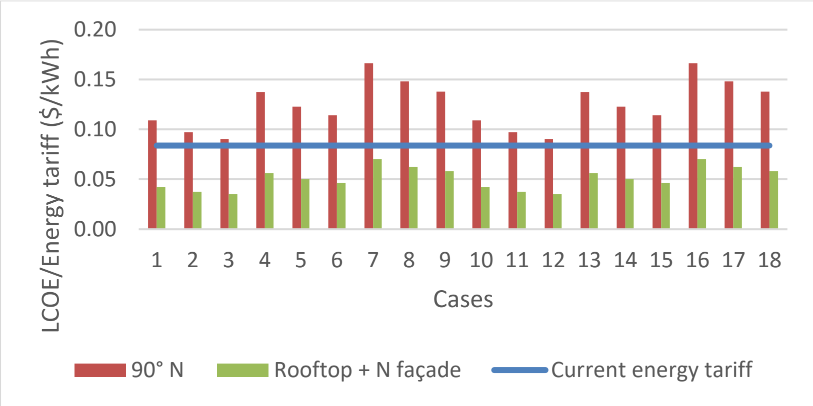


Figure 98 – LCOE for building F's 18 economic cases.



4.8 ANALYSIS' SUMMARY

Table 15 shows the total PV installed capacity and energy generation of the buildings that were accepted by the technical and economical acceptance criteria. The mini generator total installed capacity is of approximately 1.06 MWp, so the objective to propose a 1 MWp mini generator to the university was reached.

Table 15 – Selected buildings' PV installed capacity and energy generation.

Building	Installed capacity (kWp)	Energy generation (MWh/year)
A	581.80	648.06
B	54.42	42.80
C	56.30	67.90
D	115.84	125.93
E	93.44	71.62
F	153.60	188.35
Total	**1,055.40**	**1,144.66**

All of the proposed PV systems played a role in the architecture of the building, either by improving the buildings' thermal and visual comforts, or just by not having an impact in the architecture of the building at all (which is a positive aspect in this case, because the PV systems followed the buildings' shapes).

The economic analysis of the façades was not very attractive, but with the incorporation of rooftop systems, the PV integrations had better economic results.

On the buildings' economic analysis, it could be observed that the NPVs, with the addition of installed power, gets higher when positive and lower when negative, and that the PV systems' yields have a big influence on the IRRs, PBTs and LCOEs of the PV systems.

Figure 99 shows a summary of the complete PV systems' (rooftops plus considered buildings' façades) NPVs, Figure 100 the MARRs, Figure 101 the DPBTs and Figure 102 the LCOEs.

It is possible to conclude that building A had the best NPV results, followed by building F, building D, building C, building E and building B, respectively. Building F had the best IRR results, followed by building C, then building A, building D, building E and building B. Buildings' C and F DPBTs were the best ones, followed by building A, building D, building E and building B. The best LCOEs results are from building F, then building C, building A, building D, building E and building B, respectively.

In general, then, buildings A and F were the most viable ones in economic terms, and buildings B and E, the least economic feasible ones.

Figure 99 – Summary of the complete PV systems' NPVs.

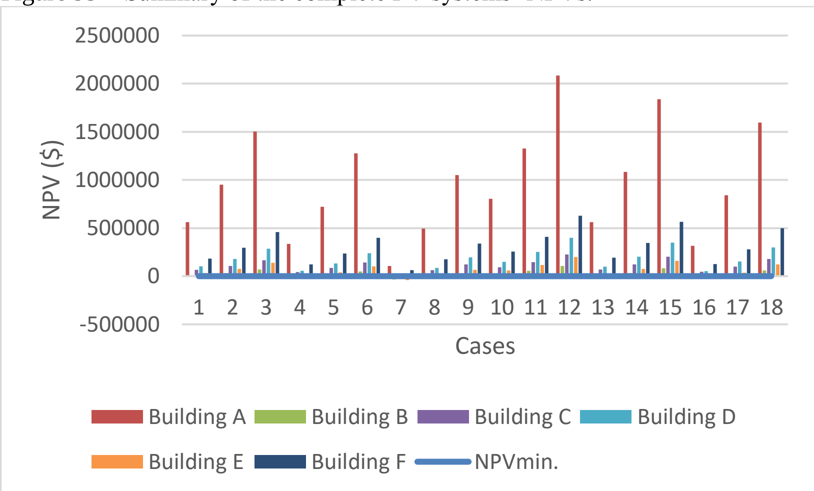


Figure 100 - Summary of the complete PV systems' IRRs.

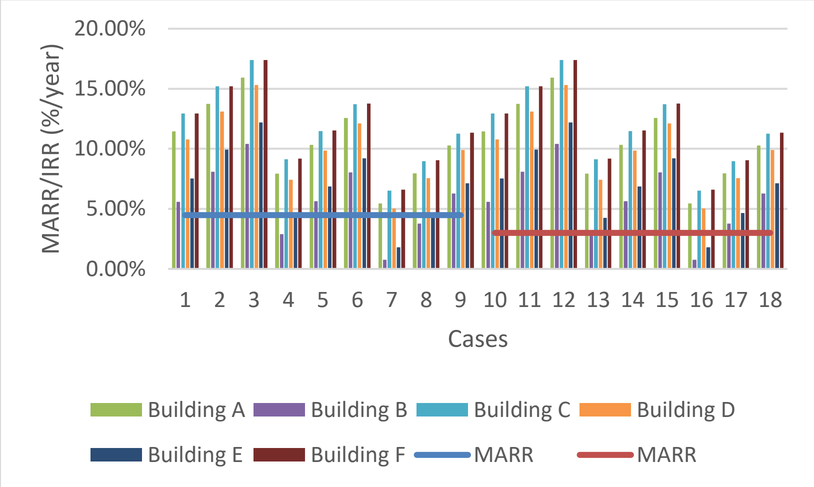


Figure 101 - Summary of the complete PV systems' DPBTs.

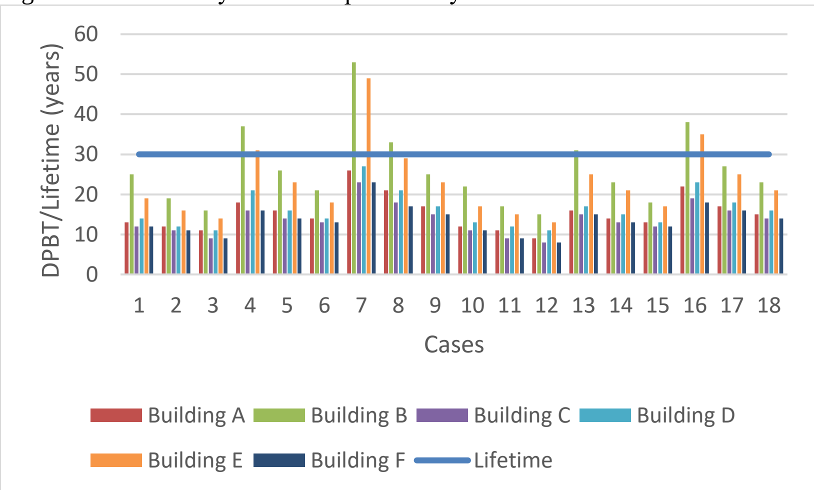
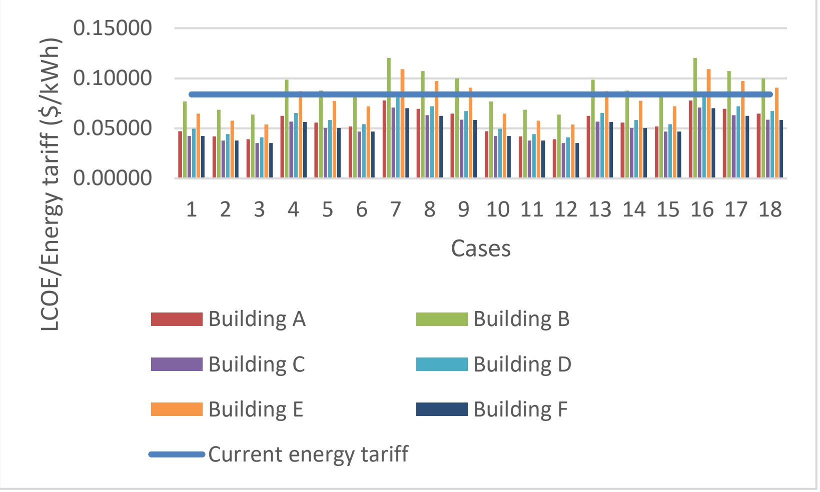


Figure 102 - Summary of the complete PV systems' LCOEs.



4.9 MINIGERATOR CONTRIBUTIONS TO THE UNIVERSITY

Table 16 shows the monthly and annual generation of the 1 MWp mini generator detailed in this work and Figure 103 shows the mini generator's energy production compared to the CU's *Cidade Universitária* energy consumption from August 2017 to July 2018.

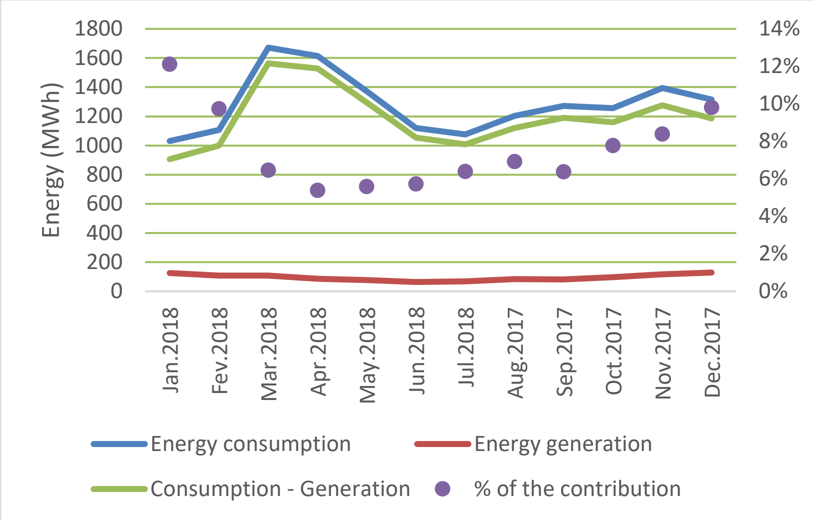
The total annual energy generation is of 1,144.66 MWh, while the total energy consumption was of 15,432.24 MWh and the off-peak hours consumption was of 14,041.44 MWh.

The 1 MWp mini generator would reduce the annual CU's energy consumption in up to 7.42%, with the highest contribution taking place in January (12.10%) and the lowest one in April (5.38%). If only off-peak hours were considered, the energy consumption would be reduced in up to 8.15%.

Table 16 – Monthly and annual energy generation of the 1 MWp generator.

Building	**A**	**B**	**C**	**D**	**E**	**F**
Month	**Energy generation (MWh)**					
Jan	73.25	3.36	7.43	14.56	6.16	19.98
Feb	62.36	3.35	6.42	12.25	5.90	17.43
Mar	61.11	4.04	6.45	11.88	6.81	17.70
Apr	47.85	3.85	5.16	9.19	6.32	14.52
May	41.05	4.04	4.51	7.75	6.29	13.20
Jun	33.87	3.51	3.73	6.34	5.50	11.05
Jul	36.73	3.68	4.02	6.88	5.68	11.84
Aug	45.38	3.96	4.92	8.63	6.27	14.05
Sep	45.59	3.10	4.80	8.90	5.36	13.31
Oct	56.24	3.21	5.81	11.08	5.55	15.88
Nov	68.51	3.29	6.98	13.48	5.73	18.80
Dec	76.12	3.42	7.67	14.98	6.06	20.62
Total per building	**648.06**	**42.80**	**67.90**	**125.93**	**71.62**	**188.35**
Total	**1,144.66**					

Figure 103 – Comparison of the 1 MWp mini generator energy production with the CU’s consumption.



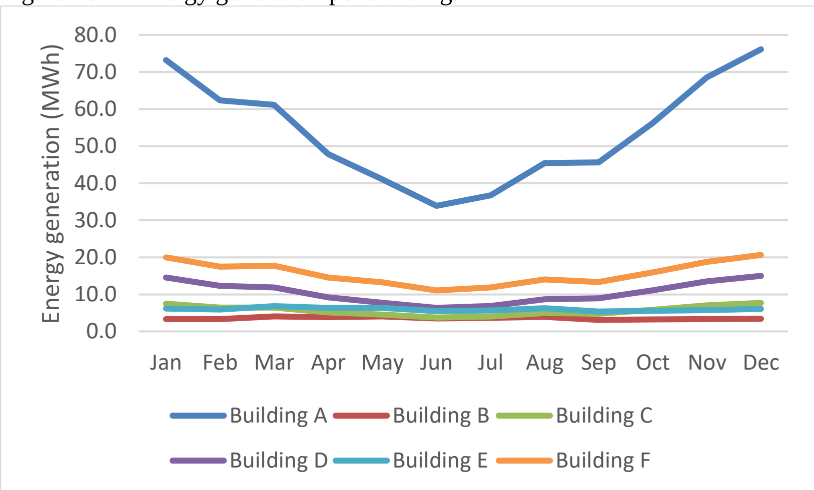
5 FINAL CONSIDERATIONS

Analyses of the technical and economic viability of PV systems integrated to façades and rooftops were carried out for the existing buildings of a Brazilian university located at a low latitude site. The objective was to create a viable 1 MWp mini generator and analyze its impact in the university's energy consumption.

The study showed that the installation of a 1 MWp mini generator on the façades (by the creation of *brise soleil* and double-skin façades) and rooftops could contribute to the architectural design and to the thermal and visual comforts of the buildings, besides reducing in up to 7.42% the university's annual energy consumption.

6 buildings were analyzed: buildings A, B, C, D, E and F. Figure 104 shows the energy contribution of each of the buildings. It can be seen that building A, where the integration was made on the rooftop and on North, East and West façades, was the building that most contributed to the reduction of the university's energy consumption.

Figure 104 – Energy generation per building.



The economic analysis was made through the calculation of the NPVs, IRRs, DPBTs and LCOEs. 18 economic scenarios were studied for each building, with variances on the TMAs, CAPEXs and annual energy tariff variations.

The research showed viable technical studies for the façades, but the economic analysis was not very attractive. However, with the addition of rooftop systems, more cases have become economically feasible and therefore attractive and valuable to be built.

Considering the worst CAPEX scenario of $1.35/Wp (R$5.00/Wp), the university would have to spend $854,874.00 (R$3,166,200.00) to install the 1 MWp mini generator. A way to encourage the institution to make this investment would be its visibility all over the country because of such a technological investment, besides the savings of about $189.000/year (R$700,000.00/year) on the energy bills.

This study has demonstrated that it is important for building designers to be aware of the possibilities, functionality and integration of PV systems and their opportunity to be economically viable.

With the declining cost of PV systems (INSTITUTO IDEAL, 2018) and the increasing cost of electric tariff in Brazil (ANEEL 2013, 2014, 2015a, 2016b, 2017b), PV façades should start to be economic feasible in more flexible ways. Consequently, PV technology could offer attractive solutions of high-tech integration and aesthetic appeal, as well as renewable and pollution-free energy generation.

5.1 SUGGESTIONS FOR FUTURE WORKS

Based on the studies and results presented in this thesis, some ideas for future works can be thought:

- The creation of a more visual method, with abacuses and schemes, to simplify the study of technical and economic viability of PV systems;
- The calculation of the impact façade PV installations (*brise soleil* and double-skin façades) have in the buildings' energy consumption, due to its alterations on thermal and visual comforts;
- A sensitivity analysis on the economic evaluation, to see how the PV systems could be more attractive in economic terms.

REFERENCES

ANEEL. **Bandeiras Tarifárias**. 2017a. Available at: <www.aneel.gov.br/bandeiras-tarifarias>.

ANEEL. **BIG - Banco de Informações de Geração**. 2018. Available at: <www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm>.

ANEEL. **Por Dentro da Conta de Luz**. Brasília, 2016a.

ANEEL. **Resolução Homologatória n° 1.617, de 17 de setembro de 2013**. 2013.

ANEEL. **Resolução Homologatória n° 1.794, de 16 de setembro de 2014**. 2014.

ANEEL. **Resolução Homologatória n° 1.927, de 4 de agosto de 2015**. 2015a.

ANEEL. **Resolução Homologatória n° 2.120, de 16 de agosto de 2016**. 2016b.

ANEEL. **Resolução Homologatória nº 2.286, de 15 de agosto de 2017**. 2017b.

ANEEL. **Resolução Normativa n° 482, de 17 de abril de 2012**. 2012.

ANEEL. **Resolução Normativa n° 687, de 24 de novembro de 2015**. 2015b.

AUTODESK. **Ecotect Analysis Discontinuation FAQ**. 2015. Available at: <www.knowledge.autodesk.com/support/ecotect-analysis/learn-explore/caas/sfdcarticles/sfdcarticles/Ecotect-Analysis-Discontinuation-FAQ.html>.

BCB. **Remuneração dos Depósitos de Poupança**. 2017. Available at: <www.bcb.gov.br/acessoinformacao/legado?url=https:%2F%2Fwww4.bcb.gov.br%2Fpec%2Fpoupanca%2Fpoupanca.asp>.

BNDES. **Fundo Clima - Subprograma Energias Renováveis**. 2017. Available at: <www.bndes.gov.br/wps/portal/site/home/financiamento/produto/fundo-clima-energias-renovaveis>.

BRANKER, K.; PATHAK, M. J. M.; PEARCE, J. M. A review of solar photovoltaic levelized cost of electricity. **Renewable and Sustainable Energy Reviews**, v. 15, n. 9, p. 4470–4482, 2011. Elsevier Ltd. Available at: <www.linkinghub.elsevier.com/retrieve/pii/S1364032111003492>.

BYD. **Series BYD P6D-36 4BB datasheet**. China, 2017.

CELESC. **Faturas de Energia Elétrica Mensais da Unidade Consumidora Cidade Universitária**. Florianópolis, 2017.

CELESC. **Faturas de Energia Elétrica Mensais da Unidade Consumidora Cidade Universitária**. Florianópolis, 2018.

CHALASANI, S.; CONRAD, J. M. A survey of energy harvesting sources for embedded systems. IEEE SoutheastCon 2008, Huntsville, AL, USA. **IEEE SoutheastCon 2008 Proceedings**, 2008. p. 442-447.

CHIVELET, N. M.; SOLLA, I. F. **Técnicas de Vedação Fotovoltaica da Arquitetura**. Barcelona: Artmed, 2007.

CÔRTES, J. G. P. **Introdução à Economia da Engenharia: uma visão do processo de gerenciamento de ativos de engenharia**. São Paulo, 2012.

DÁVI, G. A.; CAAMAÑO-MARTÍN, E.; RÜTHER, R.; SOLANO, J. Energy performance evaluation of a net plus-energy residential building with grid-connected photovoltaic system in Brazil. **Energy and Buildings**, v. 120, p. 19–29, 2016.

DIDONÉ, E. L.; WAGNER, A. Semi-transparent PV windows: A study for office buildings in Brazil. **Energy and Buildings**, v. 67, p. 136-142, 2013.

DPAE. **Localização das faturas de energia elétrica**. 2017. Available at: <www.dpae.seoma.ufsc.br/mapas/>.

ENEL SOLUÇÕES. Tudo Sobre Energia Solar: Tipos de Sistema (On-Grid e Off-Grid). 2016. Available at: <www.enelsolucoes.com.br/blog/2016/06/energia-solar-tipos-de-sistema-on-grid-e-off-grid/>.

EVOLA, G.; MARGANI, G. Renovation of apartment blocks with BIPV: Energy and economic evaluation in temperate climate. **Energy and Buildings**, v. 130, p. 794–810, 2016.

FAHRENBRUCH, A.; BUBE, R. **Fundamentals of solar cells: photovoltaic solar energy conversion**. Elsevier, 2012. 580 p.

GOOGLE. **SketchUp**. 2017. Available at: <www.sketchup.com>.

GRAU, T. et al. Survey of photovoltaic industry and policy in germany and china. **Energy Policy**, v. 51, p. 20-37, 2012.

HICKEL, B.; ANTONIOLLI, A.; DESCHAMPS, E.; PINHEIRO, E.; RÜTHER, R. **Análise da influência do acúmulo de sujeira sobre diferentes tecnologias de módulos FV: revisão e medições de campo**. VI Congresso Brasileiro de Energia Solar. Belo Horizonte, 2016.

HICKEL, B.; DESCHAMPS, E.; NASCIMENTO, L.; RÜTHER, R.; SIMÕES, G. **Análise técnica e financeira com foco na redução de perdas por mismatch no contexto do projeto 120 telhados**. V Congresso Brasileiro de Energia Solar. Recife, 2014.

HUSSEIN, H. M. S.; AHMAD, G. E.; EL-GHETANY, H. H. Performance evaluation of photovoltaic modules at different tilt angles and orientations. **Energy Conversion and Management**, v. 45, n. 15–16, p. 2441–2452, 2004.

IEA. International Energy Agency. **Key World Energy Statistics**. 2018. Available at: <www.webstore.iea.org/key-world-energy-statistics-2018>.

INSTITUTO IDEAL. **O Mercado Brasileiro de Geração Distribuída Fotovoltaica**. Florianópolis, 2018.

ISE. Fraunhofer Institute for Solar Energy Systems ISE. **Photovoltaics Report**. 2018. Available at: <www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf>.

KAHOULI-BRAHMI, S. Technological learning in energy–environment–economy modelling: a survey. **Energy Policy**, v. 36, p. 138-162, 2008.

LABSOL/UFRGS. **RADIASOL**. 2001. Available at: <www.solar.ufrgs.br/#softwares>.

LACCHINI, C.; RÜTHER, R. The influence of government strategies on the financial return of capital invested in PV systems located in different climatic zones in Brazil. **Renewable Energy**, v. 83, p. 786-798, 2015.

LAMBERTS, R.; DUTRA, L.; PEREIRA, F. O. R. **Eficiência Energética na Arquitetura**. 3. ed. Rio de Janeiro: 2014. 366 p. Available at: <www.labeee.ufsc.br/sites/default/files/apostilas/eficiencia_energetica_na_arquitetura.pdf>.

LIMMANEE, A.; SONGTRAI, S.; UDOMDACHANUT, N.; et al. Degradation analysis of photovoltaic modules under tropical climatic conditions and its impacts on LCOE. **Renewable Energy**, v. 102, p. 199–204, 2017. Elsevier Ltd. Available at: <dx.doi.org/10.1016/j.renene.2016.10.052>.

MARSH, A. **Andrew's Blog**. 2018. Available at: <www.andrewmarsh.com/>.

MEHLERI, E. D.; ZERVAS, P. L.; SARIMVEIS, H.; PALYVOS, J. A.; MARKATOS, N. C. Determination of the optimal tilt angle and orientation for solar photovoltaic arrays. **Renewable Energy**, v. 35, n. 11, p. 2468–2475, 2010. Elsevier Ltd. Available at: <dx.doi.org/10.1016/j.renene.2010.03.006>.

MERMOUD, A. **PVsyst**. 2018. Available at: <www.pvsyst.com>.

MUNOZ, M.A; CHENLO, F.; ALONSO-GARCÍA, M.C. Influence of initial power stabilization over crystalline-Si photovoltaic modules maximum power. **Progress in Photovoltaics: research and applications**, v. 19, p. 417-422, 2011.

PEREIRA, E. B.; MARTINS, F. R.; ABREU, S. L. DE; RÜTHER, R. **Atlas Brasileiro de Energia Solar**. 2017.

PEREZ, R.; INEICHEN, P.; SEALS, R.; MICHALSKY, J.; STEWART, R. Modeling daylight availability and irradiance components from direct and global irradiance. **Solar Energy**, v. 44, n. 5, p. 271–289, 1990.

PEREZ, R.; SEALS, R.; INEICHEN, P.; STEWART, R.; MENICUCCI, D. A new simplified version of the Perez diffuse irradiance model for tilted surfaces. **Solar Energy**, v. 39, n. 3, p. 221–231, 1987.

REICH, N. H.; MUELLER, B.; ARMBRUSTER, A.; et al. Performance ratio revisited: is PR>90% realistic? **Progress in Photovoltaics: research and applications**, v. 20, p. 717–726, 2012.

RÜTHER, R. **Edifícios solares fotovoltaicos: o potencial da geração solar fotovoltaica integrada a edificações urbanas e interligada à rede elétrica pública no Brasil**. 2004. Available at: < www.fotovoltaica.ufsc.br/sistemas/livros/livro-edificios-solares-fotovoltaicos.pdf>.

SANTOS, I.; RÜTHER, R. Limitations in solar module azimuth and tilt angles in building integrated photovoltaics at low latitude tropical sites in Brazil. **Renewable Energy**, v. 63, p. 116–124, 2014.

SOLARGIS. 2018. Available at: <www.solargis.com/maps-and-gis-data/overview/>.

SORGATO, M. J.; SCHNEIDER, K.; RÜTHER, R. Technical and economic evaluation of thin-film CdTe building-integrated photovoltaics (BIPV) replacing façade and rooftop materials in office buildings in a warm and sunny climate. **Renewable Energy**, p. 84-98, out. 2017.

TOLEDO, O. M. et al. Distributed photovoltaic generation and energy storage systems: A review. **Renewable and Sustainable Energy Reviews**, p. 506-511, 2010.

URBANETZ, J.; ZOMER, C. D.; RÜTHER, R. Compromises between form and function in grid-connected, building-integrated photovoltaics (BIPV) at low-latitude sites. **Building and Environment**, v. 46, n. 10, p. 2107–2113, 2011. Elsevier Ltd. Available at: <dx.doi.org/10.1016/j.buildenv.2011.04.024>.

ZOMER, C. **Método de estimativa da influência do sombreamento parcial na geração energética de sistemas solares fotovoltaicos integrados em edificações**. 2014. 234 p. Tese (Doutorado em Engenharia Civil) - Departamento de Engenharia Civil, Universidade Federal de Santa Catarina, Florianópolis, 2014.

ZOMER, C. D.; COSTA, M. R.; NOBRE, A.; RÜTHER, R. Performance compromises of building-integrated and building-applied photovoltaics (BIPV and BAPV) in Brazilian airports. **Energy and Buildings**, v. 66, p. 607–615, 2013. Elsevier B.V. Available at: <dx.doi.org/10.1016/j.enbuild.2013.07.076>. .

ZUMTHOR, P. **Pensar a arquitectura**. São Paulo: GG, 2009. 96 p.

APPENDIX A – Building A's PVsyst reports: rooftop, north façade, east façade and west façade, respectively.

PVSYST V6.74	Isadora Pauli Custodio (Brazil)	22/10/18	Page 1/6

Grid-Connected System: Simulation parameters

Project :	**Building A's rooftop**			
Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant :	**New simulation variant**			
	Simulation date	22/10/18 11h25		

Simulation parameters	System type	**Sheds on a building**		
2 orientations	tilts/azimuths	5°/-95° and 5°/85°		
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Arrays Characteristics (8 kinds of array defined)				
PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Sub-array "Sub-array #1"	Orientation	**#1**	Tilt/Azimuth	5°/-95°
Number of PV modules	In series	10 modules	In parallel	32 strings
Total number of PV modules	Nb. modules	320	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**102 kWp**	At operating cond.	87.7 kWp (60°C)
Array operating characteristics (50°C)	U mpp	317 V	I mpp	277 A
Sub-array "Sub-array #2"	Orientation	**#1**	Tilt/Azimuth	5°/-95°
Number of PV modules	In series	10 modules	In parallel	32 strings
Total number of PV modules	Nb. modules	320	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**102 kWp**	At operating cond.	87.7 kWp (60°C)
Array operating characteristics (50°C)	U mpp	317 V	I mpp	277 A
Sub-array "Sub-array #3"	Orientation	**#2**	Tilt/Azimuth	5°/85°
Number of PV modules	In series	10 modules	In parallel	32 strings
Total number of PV modules	Nb. modules	320	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**102 kWp**	At operating cond.	87.7 kWp (60°C)
Array operating characteristics (50°C)	U mpp	317 V	I mpp	277 A
Sub-array "Sub-array #4"	Orientation	**#2**	Tilt/Azimuth	5°/85°
Number of PV modules	In series	10 modules	In parallel	32 strings
Total number of PV modules	Nb. modules	320	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**102 kWp**	At operating cond.	87.7 kWp (60°C)
Array operating characteristics (50°C)	U mpp	317 V	I mpp	277 A
Sub-array "Sub-array #5"	Orientation	**#1**	Tilt/Azimuth	5°/-95°
Number of PV modules	In series	12 modules	In parallel	11 strings
Total number of PV modules	Nb. modules	132	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**42.2 kWp**	At operating cond.	36.2 kWp (60°C)
Array operating characteristics (50°C)	U mpp	380 V	I mpp	95 A
Sub-array "Sub-array #6"	Orientation	**#2**	Tilt/Azimuth	5°/85°
Number of PV modules	In series	12 modules	In parallel	11 strings
Total number of PV modules	Nb. modules	132	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**42.2 kWp**	At operating cond.	36.2 kWp (60°C)
Array operating characteristics (50°C)	U mpp	380 V	I mpp	95 A

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Grid-Connected System: Simulation parameters

Sub-array "Sub-array #7"	Orientation	#1	Tilt/Azimuth	5°/-95°
Number of PV modules	In series	14 modules	In parallel	3 strings
Total number of PV modules	Nb. modules	42	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**13.44 kWp**	At operating cond.	11.52 kWp (60°C)
Array operating characteristics (50°C)	U mpp	444 V	I mpp	26 A
Sub-array "Sub-array #8"	Orientation	#2	Tilt/Azimuth	5°/85°
Number of PV modules	In series	14 modules	In parallel	3 strings
Total number of PV modules	Nb. modules	42	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**13.44 kWp**	At operating cond.	11.52 kWp (60°C)
Array operating characteristics (50°C)	U mpp	444 V	I mpp	26 A
Total Arrays global power	Nominal (STC)	**521 kWp**	Total	1628 modules
	Module area	**3225 m²**	Cell area	2853 m²

Sub-array "Sub-array #1" : Inverter	Model	**SKN 411**		
Original PVsyst database	Manufacturer	Solar Konzept		
Characteristics	Operating Voltage	300-450 V	Unit Nom. Power	100 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	100 kWac
			Pnom ratio	1.02
Sub-array "Sub-array #2" : Inverter	Model	**SKN 411**		
Original PVsyst database	Manufacturer	Solar Konzept		
Characteristics	Operating Voltage	300-450 V	Unit Nom. Power	100 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	100 kWac
			Pnom ratio	1.02
Sub-array "Sub-array #3" : Inverter	Model	**SKN 411**		
Original PVsyst database	Manufacturer	Solar Konzept		
Characteristics	Operating Voltage	300-450 V	Unit Nom. Power	100 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	100 kWac
			Pnom ratio	1.02
Sub-array "Sub-array #4" : Inverter	Model	**SKN 411**		
Original PVsyst database	Manufacturer	Solar Konzept		
Characteristics	Operating Voltage	300-450 V	Unit Nom. Power	100 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	100 kWac
			Pnom ratio	1.02
Sub-array "Sub-array #5" : Inverter	Model	**Solargate PV7L052NN**		
Original PVsyst database	Manufacturer	Nidec ASI S.p.A.		
Characteristics	Operating Voltage	320-630 V	Unit Nom. Power	42.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	42 kWac
			Pnom ratio	1.01
Sub-array "Sub-array #6" : Inverter	Model	**Solargate PV7L052NN**		
Original PVsyst database	Manufacturer	Nidec ASI S.p.A.		
Characteristics	Operating Voltage	320-630 V	Unit Nom. Power	42.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	42 kWac
			Pnom ratio	1.01
Sub-array "Sub-array #7" : Inverter	Model	**Platinum 13000 TLD 749842**		
Original PVsyst database	Manufacturer	Platinum GmbH (Diehl)		
Characteristics	Operating Voltage	351-710 V	Unit Nom. Power	12.4 kWac
Inverter pack	Nb. of inverters	3 * MPPT 33 %	Total Power	12.4 kWac
			Pnom ratio	1.08
Sub-array "Sub-array #8" : Inverter	Model	**Platinum 13000 TLD 749842**		
Original PVsyst database	Manufacturer	Platinum GmbH (Diehl)		
Characteristics	Operating Voltage	351-710 V	Unit Nom. Power	12.4 kWac
Inverter pack	Nb. of inverters	3 * MPPT 33 %	Total Power	12.4 kWac
			Pnom ratio	1.08
Total	Nb. of inverters	8	Total Power	509 kWac

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Grid-Connected System: Simulation parameters

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	20 mOhm	Loss Fraction	1.5 % at STC
	Array#2	20 mOhm	Loss Fraction	1.5 % at STC
	Array#3	20 mOhm	Loss Fraction	1.5 % at STC
	Array#4	20 mOhm	Loss Fraction	1.5 % at STC
	Array#5	71 mOhm	Loss Fraction	1.5 % at STC
	Array#6	71 mOhm	Loss Fraction	1.5 % at STC
	Array#7	304 mOhm	Loss Fraction	1.5 % at STC
	Array#8	304 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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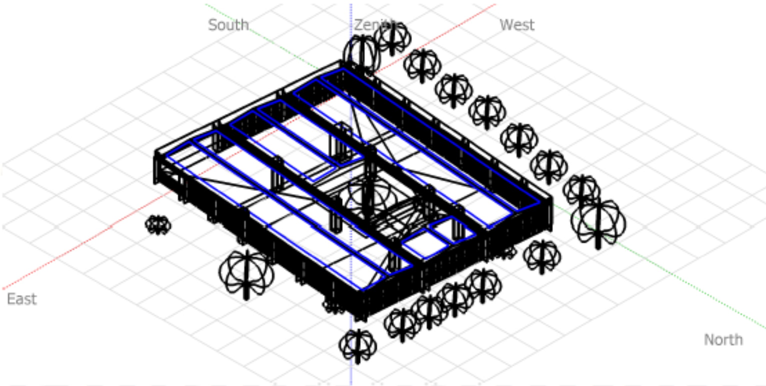
Grid-Connected System: Near shading definition

Project : **Building A's rooftop**

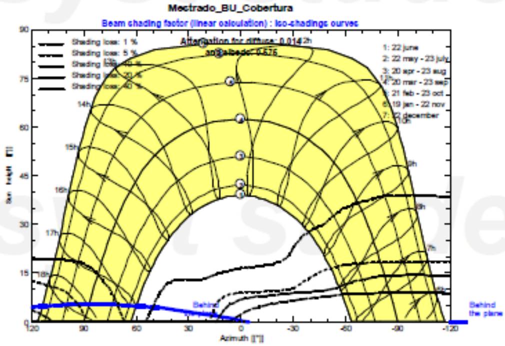
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	2 orientations	Tilt/Azimuth = 5°/-95° and 5°/85°		
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	1628	Pnom total	**521 kWp**
Inverter	Model	SKN 411	Pnom	100 kW ac
Inverter	Model	Solargate PV7L052NN	Pnom	42.0 kW ac
Inverter	Model	Platinum 13000 TLD 749842	Pnom	12.40 kW ac
Inverter pack	Nb. of units	8.0	Pnom total	**509 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

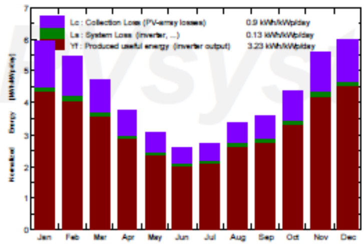
Project : **Building A's rooftop**

Simulation variant : **New simulation variant**

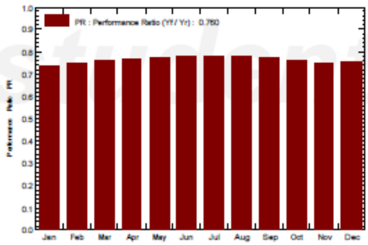
Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	2 orientations	Tilt/Azimuth = 5°/-95° and 5°/85°		
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	1628	Pnom total	**521 kWp**
Inverter	Model	SKN 411	Pnom	100 kW ac
Inverter	Model	Solargate PV7L052NN	Pnom	42.0 kW ac
Inverter	Model	Platinum 13000 TLD 749842	Pnom	12.40 kW ac
Inverter pack	Nb. of units	8.0	Pnom total	**509 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**615.0 MWh/year**	Specific prod.	1181 kWh/kWp/year
	Performance Ratio PR	75.97 %		

Normalized productions (per installed kWp): Nominal power 521 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	183.6	170.3	72.94	70.30	0.735
February	152.9	78.73	23.90	152.7	141.6	61.80	59.55	0.748
March	146.9	75.57	22.00	146.6	135.5	60.14	57.99	0.759
April	113.1	53.88	19.70	113.0	104.1	46.79	45.02	0.765
May	94.9	44.04	17.20	94.8	86.6	39.82	38.27	0.775
June	77.7	39.89	16.60	77.6	70.7	32.86	31.51	0.780
July	84.3	43.92	16.70	84.2	76.8	35.66	34.22	0.780
August	104.8	54.18	17.40	104.7	96.2	44.26	42.55	0.780
September	108.0	62.69	18.80	107.8	99.2	44.96	43.20	0.769
October	135.2	79.69	20.70	135.0	124.5	55.65	53.57	0.762
November	168.3	82.61	22.70	168.0	156.0	68.15	65.70	0.751
December	186.6	90.05	21.30	186.3	173.2	75.88	73.16	0.754
Year	1556.5	787.40	20.12	1554.1	1434.6	638.91	615.04	0.760

Legends:				
GlobHor	Horizontal global irradiation		GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation		EArray	Effective energy at the output of the array
T Amb	Ambient Temperature		E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane		PR	Performance Ratio

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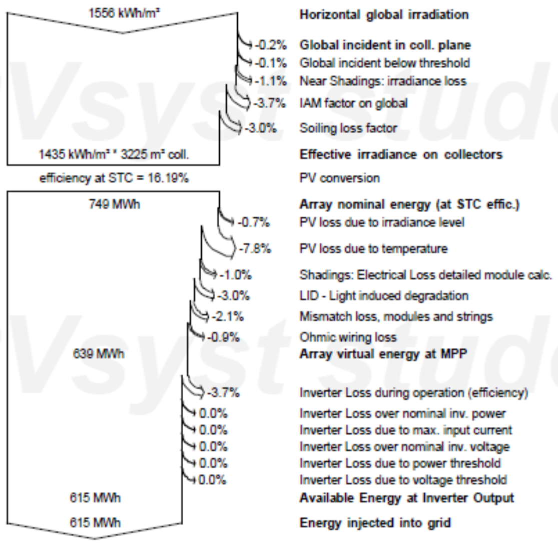
Grid-Connected System: Loss diagram

Project : **Building A's rooftop**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	2 orientations	Tilt/Azimuth = 5°/-95° and 5°/85°		
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	1628	Pnom total	**521 kWp**
Inverter	Model	SKN 411	Pnom	100 kW ac
Inverter	Model	Solargate PV7L052NN	Pnom	42.0 kW ac
Inverter	Model	Platinum 13000 TLD 749842	Pnom	12.40 kW ac
Inverter pack	Nb. of units	8.0	Pnom total	**509 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : Building A's north façade

Geographical Site		**Florianópolis_Atlas2017**		Country	**Brazil**
Situation		Latitude	-27.59° S	Longitude	-48.55° W
Time defined as		Legal Time	Time zone UT-3	Altitude	3 m
		Albedo	0.20		
Meteo data:		**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : New simulation variant

Simulation date 30/10/18 13h32

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	90°	Azimuth	-5°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Arrays Characteristics (3 kinds of array defined)

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Sub-array "Sub-array #1"				
Number of PV modules	In series	5 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	20	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**6.40 kWp**	At operating cond.	5.48 kWp (60°C)
Array operating characteristics (50°C)	U mpp	159 V	I mpp	35 A
Sub-array "Sub-array #2"				
Number of PV modules	In series	5 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	20	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**6.40 kWp**	At operating cond.	5.48 kWp (60°C)
Array operating characteristics (50°C)	U mpp	159 V	I mpp	35 A
Sub-array "Sub-array #3"				
Number of PV modules	In series	5 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	20	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**6.40 kWp**	At operating cond.	5.48 kWp (60°C)
Array operating characteristics (50°C)	U mpp	159 V	I mpp	35 A
Total Arrays global power	Nominal (STC)	**19 kWp**	Total	60 modules
	Module area	**119 m²**	Cell area	105 m²

Inverter	Model	**APV 1700-2M-TL**		
Original PVsyst database	Manufacturer	Gefran S.p.A		
Characteristics	Operating Voltage	120-450 V	Unit Nom. Power	1.60 kWac
Sub-array "Sub-array #1"	Nb. of inverters	4 units	Total Power	6.4 kWac
			Pnom ratio	1.00
Sub-array "Sub-array #2"	Nb. of inverters	4 units	Total Power	6.4 kWac
			Pnom ratio	1.00
Sub-array "Sub-array #3"	Nb. of inverters	4 units	Total Power	6.4 kWac
			Pnom ratio	1.00
Total	Nb. of inverters	12	Total Power	19 kWac

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s

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Grid-Connected System: Simulation parameters

Wiring Ohmic Loss	Array#1	82 mOhm	Loss Fraction	1.5 % at STC
	Array#2	82 mOhm	Loss Fraction	1.5 % at STC
	Array#3	82 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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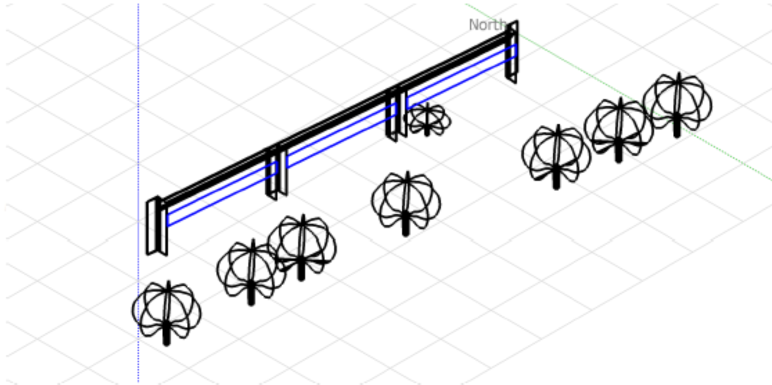
Grid-Connected System: Near shading definition

Project : **Building A's north façade**

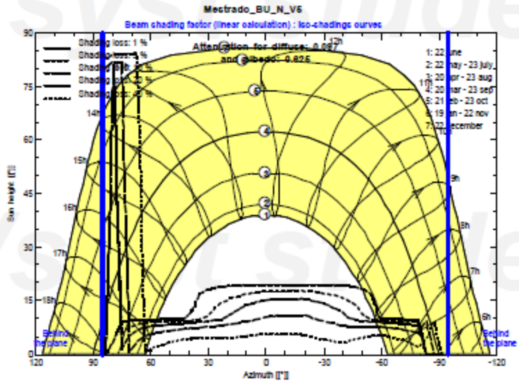
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	60	Pnom total	**19.20 kWp**
Inverter	Model	APV 1700-2M-TL	Pnom	1600 W ac
Inverter pack	Nb. of units	12.0	Pnom total	**19.20 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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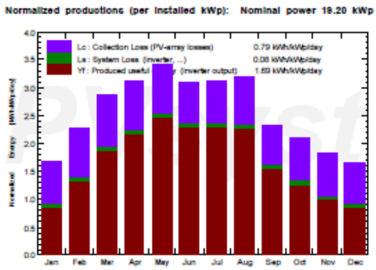
Grid-Connected System: Main results

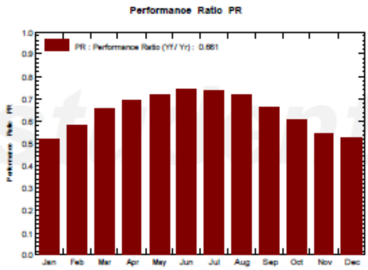
Project : **Building A's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	60	Pnom total	**19.20 kWp**
Inverter	Model	APV 1700-2M-TL	Pnom	1600 W ac
Inverter pack	Nb. of units	12.0	Pnom total	**19.20 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	Produced Energy	**11.85 MWh/year**	Specific prod.	617 kWh/kWp/year
	Performance Ratio PR	66.12 %		





New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	51.9	34.12	0.562	0.515	0.516
February	152.9	78.73	23.90	63.5	44.86	0.754	0.714	0.585
March	146.9	75.57	22.00	88.8	68.13	1.158	1.113	0.652
April	113.1	53.88	19.70	93.5	76.28	1.297	1.250	0.696
May	94.9	44.04	17.20	106.1	90.29	1.521	1.470	0.722
June	77.7	39.89	16.60	93.2	79.99	1.371	1.326	0.742
July	84.3	43.92	16.70	96.7	82.57	1.415	1.368	0.737
August	104.8	54.18	17.40	98.4	81.81	1.404	1.356	0.717
September	108.0	62.69	18.80	70.2	54.34	0.932	0.889	0.660
October	135.2	79.69	20.70	64.9	47.12	0.801	0.755	0.606
November	168.3	82.61	22.70	54.9	36.68	0.614	0.574	0.544
December	186.6	90.05	21.30	51.0	33.47	0.558	0.517	0.527
Year	1556.5	787.41	20.12	933.2	729.64	12.384	11.846	0.661

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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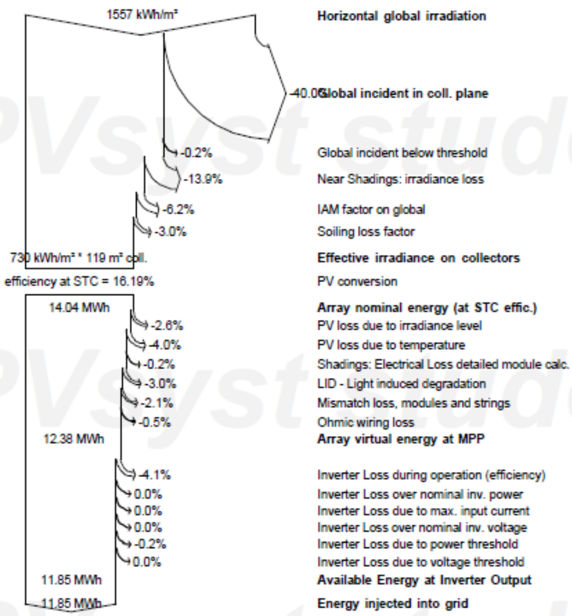
Grid-Connected System: Loss diagram

Project : **Building A's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**			
Near Shadings	Detailed electrical calculation	(acc. to module layout)			
PV Field Orientation	tilt	90°	azimuth	-5°	
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp	
PV Array	Nb. of modules	60	Pnom total	**19.20 kWp**	
Inverter	Model	APV 1700-2M-TL	Pnom	1600 W ac	
Inverter pack	Nb. of units	12.0	Pnom total	**19.20 kW ac**	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building A's east façade**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 13h25

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	90°	Azimuth	-95°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Array Characteristics

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	10 modules	In parallel	7 strings
Total number of PV modules	Nb. modules	70	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**22.40 kWp**	At operating cond.	19.19 kWp (60°C)
Array operating characteristics (50°C)	U mpp	317 V	I mpp	61 A
Total area	Module area	**139 m²**	Cell area	123 m²

Inverter	Model	**SKN 404**		
Original PVsyst database	Manufacturer	Solar Konzept		
Characteristics	Operating Voltage	300-450 V	Unit Nom. Power	22.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	22 kWac
			Pnom ratio	1.02

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	93 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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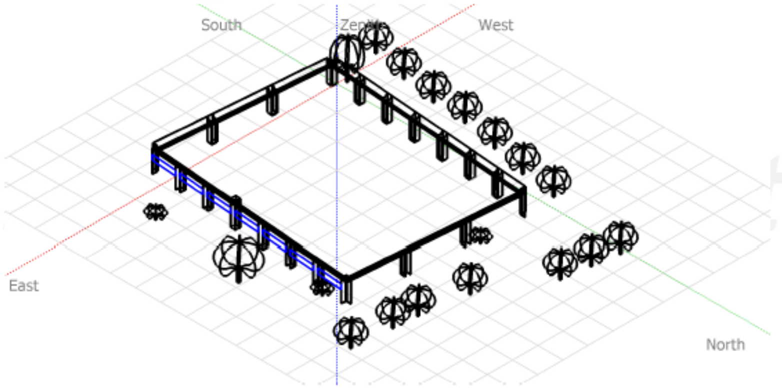
Grid-Connected System: Near shading definition

Project : **Building A's east façade**

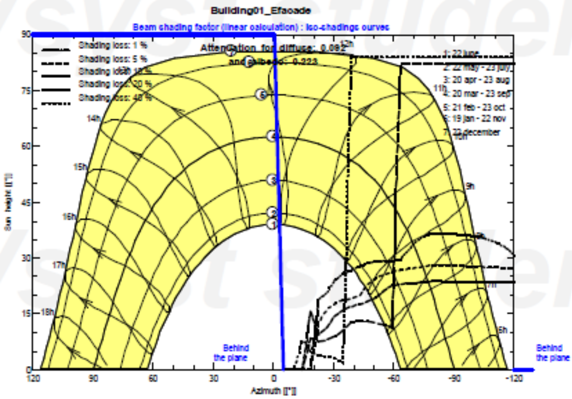
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-95°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	70	Pnom total	**22.40 kWp**
Inverter	Model	SKN 404	Pnom	22.00 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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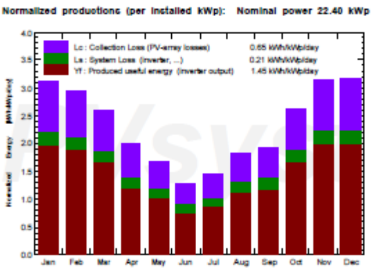
Grid-Connected System: Main results

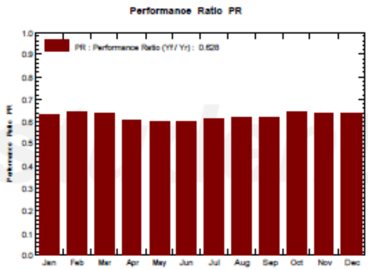
Project : **Building A's east façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-95°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	70	Pnom total	**22.40 kWp**
Inverter	Model	SKN 404	Pnom	22.00 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	Produced Energy	**11.84 MWh/year**	Specific prod.	529 kWh/kWp/year
	Performance Ratio PR	62.79 %		





New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	96.58	81.68	1.532	1.364	0.631
February	152.9	78.73	23.90	82.29	69.49	1.329	1.186	0.643
March	146.9	75.57	22.00	80.43	67.96	1.302	1.154	0.640
April	113.1	53.88	19.70	59.55	49.73	0.941	0.807	0.605
May	94.9	44.04	17.20	52.43	43.08	0.835	0.706	0.601
June	77.7	39.89	16.60	38.19	31.35	0.622	0.510	0.597
July	84.3	43.92	16.70	44.59	36.71	0.726	0.609	0.609
August	104.8	54.18	17.40	56.91	47.13	0.921	0.787	0.617
September	108.0	62.69	18.80	57.59	48.13	0.940	0.801	0.621
October	135.2	79.69	20.70	80.84	67.76	1.320	1.165	0.643
November	168.3	82.61	22.70	94.37	79.82	1.511	1.350	0.639
December	186.6	90.05	21.30	97.93	82.70	1.571	1.400	0.638
Year	1556.5	787.40	20.12	841.69	705.56	13.551	11.839	0.628

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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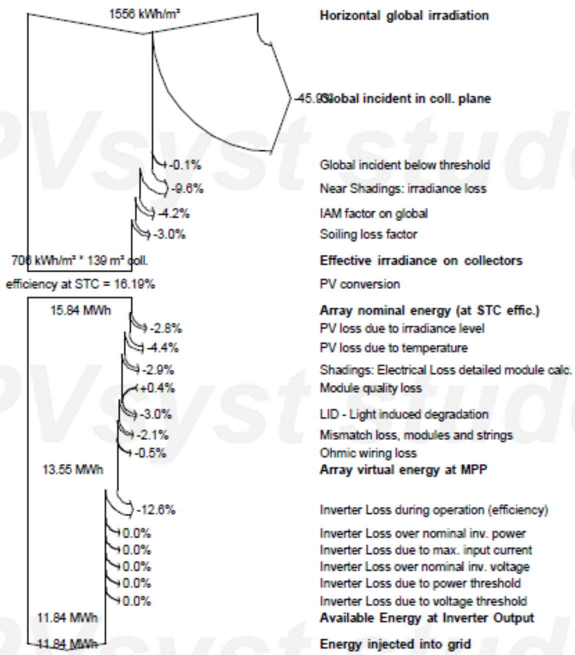
Grid-Connected System: Loss diagram

Project : **Building A’s east façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-95°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	70	Pnom total	**22.40 kWp**
Inverter	Model	SKN 404	Pnom	22.00 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building A's west façade**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 13h27

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	90°	Azimuth	85°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Array Characteristics

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	10 modules	In parallel	6 strings
Total number of PV modules	Nb. modules	60	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**19.20 kWp**	At operating cond.	16.45 kWp (60°C)
Array operating characteristics (50°C)	U mpp	317 V	I mpp	52 A
Total area	Module area	**119 m²**	Cell area	105 m²

Inverter	Model	**G-503, single**		
Original PVsyst database	Manufacturer	Leonics		
Characteristics	Operating Voltage	270-550 V	Unit Nom. Power	20.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	20 kWac
			Pnom ratio	0.96

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	109 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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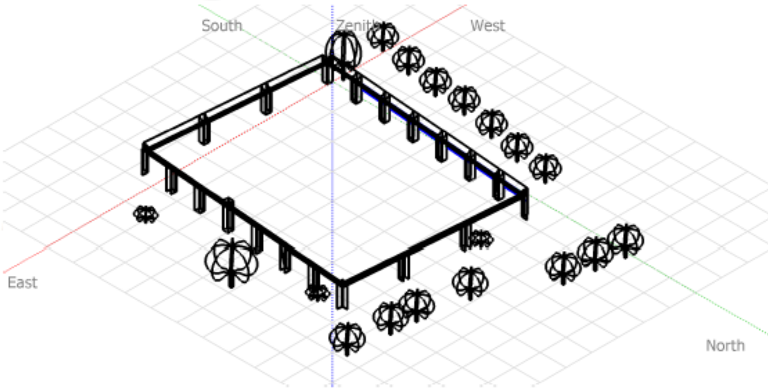
Grid-Connected System: Near shading definition

Project : **Building A's west façade**

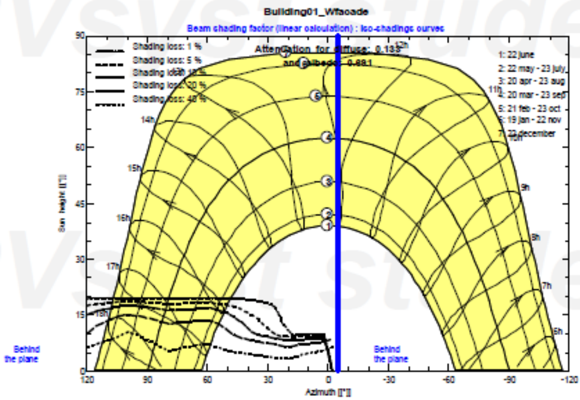
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	85°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	60	Pnom total	**19.20 kWp**
Inverter	Model	G-503, single	Pnom	20.00 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

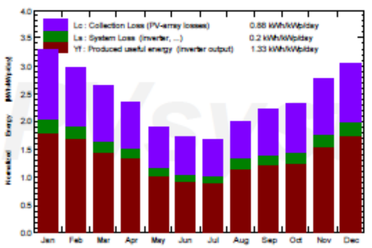
Project : **Building A's west façade**

Simulation variant : **New simulation variant**

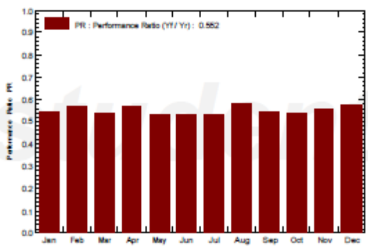
Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	85°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	60	Pnom total	**19.20 kWp**
Inverter	Model	G-503, single	Pnom	20.00 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**9.33 MWh/year**	Specific prod.	486 kWh/kWp/year
	Performance Ratio PR	55.18 %		

Normalized productions (per installed kWp): Nominal power 19.20 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	102.6	77.56	1.216	1.071	0.544
February	152.9	78.73	23.90	83.6	63.94	1.035	0.912	0.568
March	146.9	75.57	22.00	82.5	63.22	0.976	0.854	0.539
April	113.1	53.88	19.70	70.4	55.04	0.879	0.769	0.569
May	94.9	44.04	17.20	58.9	45.68	0.702	0.603	0.533
June	77.7	39.89	16.60	51.8	39.43	0.612	0.525	0.527
July	84.3	43.92	16.70	51.9	39.87	0.622	0.532	0.534
August	104.8	54.18	17.40	61.7	48.07	0.795	0.690	0.582
September	108.0	62.69	18.80	67.3	51.13	0.810	0.701	0.543
October	135.2	79.69	20.70	72.6	54.47	0.866	0.747	0.536
November	168.3	82.61	22.70	83.4	64.37	1.018	0.890	0.555
December	186.6	90.05	21.30	94.2	71.70	1.180	1.038	0.574
Year	1556.5	787.40	20.12	880.9	674.47	10.712	9.332	0.552

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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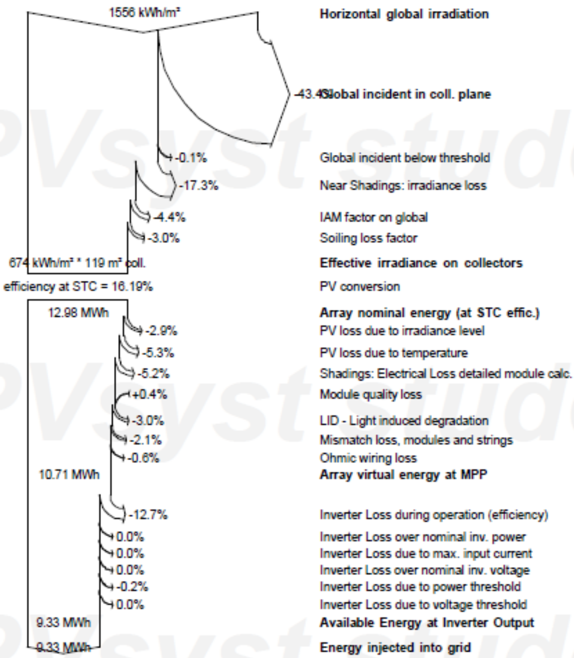
Grid-Connected System: Loss diagram

Project : **Building A's west façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	85°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	60	Pnom total	**19.20 kWp**
Inverter	Model	G-503, single	Pnom	20.00 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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APPENDIX B – Building B's PVsyst reports: rooftop and north façade, respectively.

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Grid-Connected System: Simulation parameters

Project : **Building B's rooftop**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 13h42

Simulation parameters	System type	**Building system**		
Collector Plane Orientation	Tilt	3°	Azimuth	-5°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Array Characteristics				
PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	8 modules	In parallel	7 strings
Total number of PV modules	Nb. modules	56	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**17.92 kWp**	At operating cond.	15.35 kWp (60°C)
Array operating characteristics (50°C)	U mpp	254 V	I mpp	61 A
Total area	Module area	**111 m²**	Cell area	98.1 m²
Inverter	Model	**Ingecon Sun 18 TL-Sm**		
Original PVsyst database	Manufacturer	Ingeteam		
Characteristics	Operating Voltage	189-450 V	Unit Nom. Power	18.0 kWac
Inverter pack	Nb. of inverters	3 * MPPT 33 %	Total Power	18.0 kWac
			Pnom ratio	1.00
PV Array loss factors				
Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	75 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :	Unlimited load (grid)			

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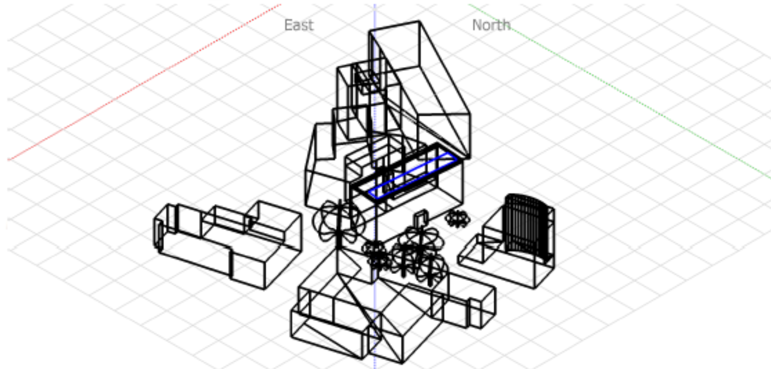
Grid-Connected System: Near shading definition

Project : **Building B's rooftop**

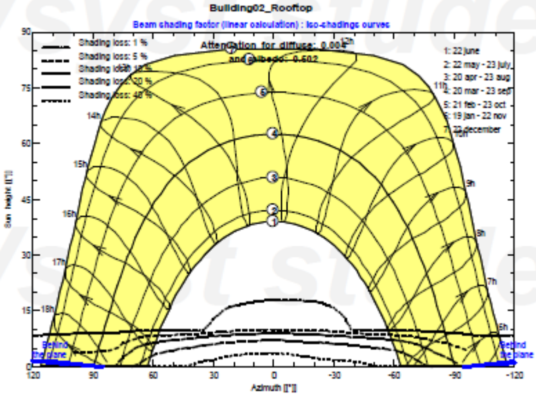
Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	3°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	56	Pnom total	**17.92 kWp**
Inverter	Model	Ingecon Sun 18 TL-Sm	Pnom	18.00 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

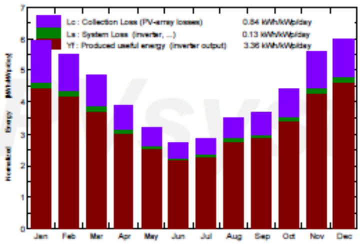
Project : **Building B's rooftop**

Simulation variant : **New simulation variant**

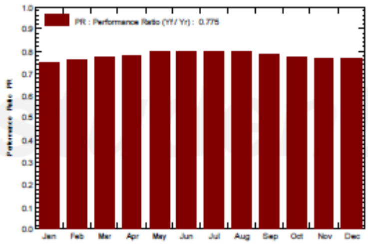
Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	3°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	56	Pnom total	**17.92 kWp**
Inverter	Model	Ingecon Sun 18 TL-Sm	Pnom	18.00 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**21.96 MWh/year**	Specific prod.	1225 kWh/kWp/year
	Performance Ratio PR	77.54 %		

Normalized productions (per installed kWp): Nominal power 17.92 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	183.5	171.5	2.568	2.473	0.752
February	152.9	78.73	23.90	153.9	143.8	2.183	2.102	0.762
March	146.9	75.57	22.00	149.3	139.1	2.149	2.071	0.774
April	113.1	53.88	19.70	116.3	108.1	1.694	1.628	0.781
May	94.9	44.04	17.20	99.0	91.5	1.467	1.408	0.793
June	77.7	39.89	16.60	81.3	74.9	1.215	1.164	0.799
July	84.3	43.92	16.70	88.0	81.2	1.312	1.258	0.797
August	104.8	54.18	17.40	108.3	100.5	1.609	1.546	0.796
September	108.0	62.69	18.80	109.8	102.0	1.611	1.545	0.785
October	135.2	79.69	20.70	136.3	126.8	1.976	1.900	0.778
November	168.3	82.61	22.70	168.5	157.5	2.396	2.308	0.764
December	186.6	90.05	21.30	186.1	174.1	2.655	2.557	0.767
Year	1556.5	787.40	20.12	1580.3	1471.1	22.835	21.959	0.775

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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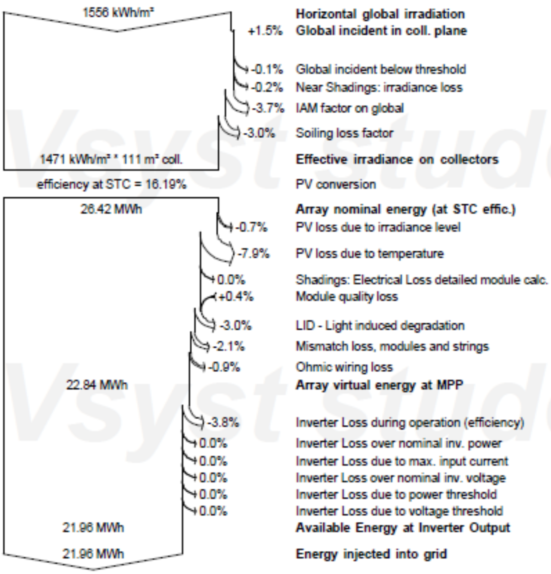
Grid-Connected System: Loss diagram

Project : **Building B's rooftop**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	3°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	56	Pnom total	**17.92 kWp**
Inverter	Model	Ingecon Sun 18 TL-Sm	Pnom	18.00 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building B's north façade**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 13h53

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	90°	Azimuth	-5°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Array Characteristics

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	19 modules	In parallel	6 strings
Total number of PV modules	Nb. modules	114	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**36.5 kWp**	At operating cond.	31.3 kWp (60°C)
Array operating characteristics (50°C)	U mpp	602 V	I mpp	52 A
Total area	Module area	**226 m²**	Cell area	200 m²

Inverter	Model	**Powador 40.0 TL3 XL**		
Original PVsyst database	Manufacturer	Kaco new energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	36.0 kWac
Inverter pack	Nb. of inverters	3 * MPPT 33 %	Total Power	36 kWac
			Pnom ratio	1.01

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	207 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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Grid-Connected System: Near shading definition

Project : **Building B's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	114	Pnom total	**36.5 kWp**
Inverter	Model	Powador 40.0 TL3 XL	Pnom	36.0 kW ac
User's needs	Unlimited load (grid)			

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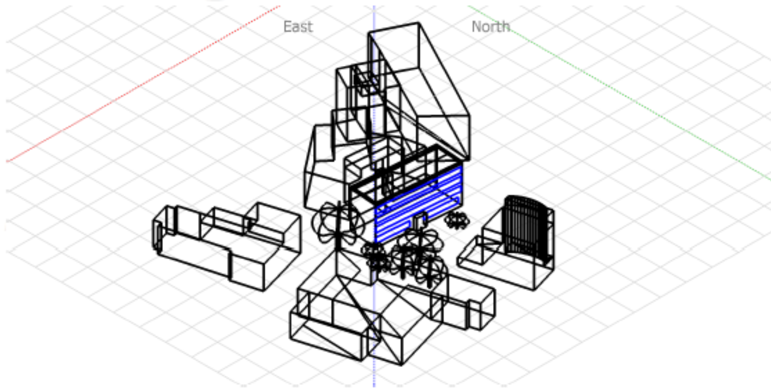
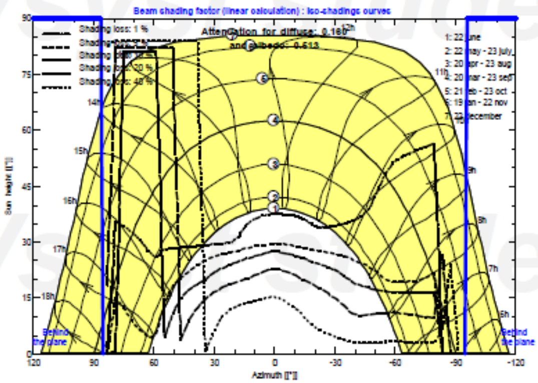
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Building02_Nfacade



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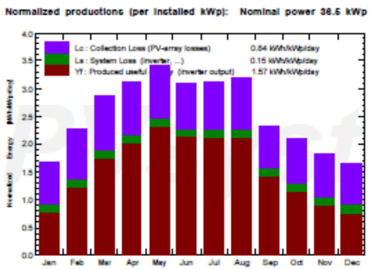
Grid-Connected System: Main results

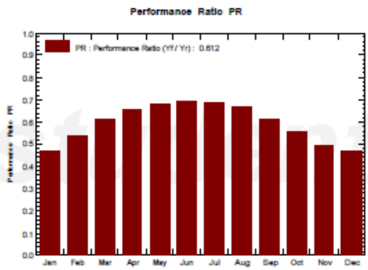
Project : **Building B's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	114	Pnom total	**36.5 kWp**
Inverter	Model	Powador 40.0 TL3 XL	Pnom	36.0 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**20.84 MWh/year**	Specific prod.	571 kWh/kWp/year
	Performance Ratio PR	61.23 %		





New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	51.9	33.81	1.059	0.882	0.465
February	152.9	78.73	23.90	63.5	44.32	1.412	1.252	0.540
March	146.9	75.57	22.00	88.8	67.04	2.141	1.966	0.607
April	113.1	53.88	19.70	93.5	74.81	2.386	2.224	0.652
May	94.9	44.04	17.20	106.1	88.38	2.792	2.629	0.679
June	77.7	39.89	16.60	93.2	78.22	2.490	2.346	0.690
July	84.3	43.92	16.70	96.7	80.64	2.567	2.419	0.686
August	104.8	54.18	17.40	98.4	80.02	2.575	2.411	0.671
September	108.0	62.69	18.80	70.2	53.20	1.713	1.553	0.607
October	135.2	79.69	20.70	64.9	46.26	1.483	1.311	0.554
November	168.3	82.61	22.70	54.9	36.28	1.154	0.983	0.491
December	186.6	90.05	21.30	51.0	33.05	1.050	0.867	0.466
Year	1556.5	787.40	20.12	933.2	716.01	22.823	20.844	0.612

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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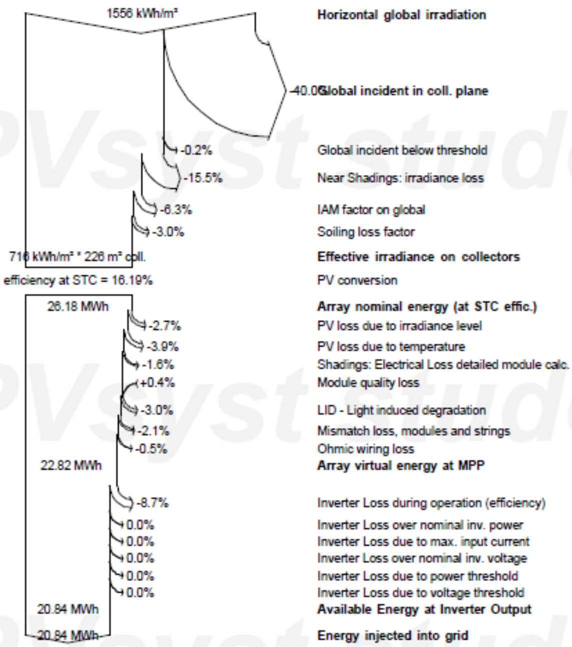
Grid-Connected System: Loss diagram

Project : **Building B's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	114	Pnom total	**36.5 kWp**
Inverter	Model	Powador 40.0 TL3 XL	Pnom	36.0 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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APPENDIX C – Building C's PVsyst report: rooftop.

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Grid-Connected System: Simulation parameters

Project : **Building C's rooftop**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 14h22

Simulation parameters		System type	**Building system**		
Collector Plane Orientation		Tilt	10°	Azimuth	-6°
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon		Free Horizon			
Near Shadings		Detailed electrical calculation	(acc. to module layout)		
PV Array Characteristics					
PV module	Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition		Manufacturer	BYD		
Number of PV modules		In series	16 modules	In parallel	11 strings
Total number of PV modules		Nb. modules	176	Unit Nom. Power	320 Wp
Array global power		Nominal (STC)	**56.3 kWp**	At operating cond.	48.3 kWp (60°C)
Array operating characteristics (50°C)		U mpp	507 V	I mpp	95 A
Total area		Module area	**349 m²**	Cell area	308 m²
Inverter		Model	**Solargate PV8L070NN**		
Original PVsyst database		Manufacturer	Nidec ASI S.p.A.		
Characteristics		Operating Voltage	430-760 V	Unit Nom. Power	57.0 kWac
Inverter pack		Nb. of inverters	1 units	Total Power	57 kWac
				Pnom ratio	0.99
PV Array loss factors					
Array Soiling Losses				Loss Fraction	3.0 %
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	95 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation				Loss Fraction	3.0 %
Module Quality Loss				Loss Fraction	-0.4 %
Module Mismatch Losses				Loss Fraction	2.0 % at MPP
Strings Mismatch loss				Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :		Unlimited load (grid)			

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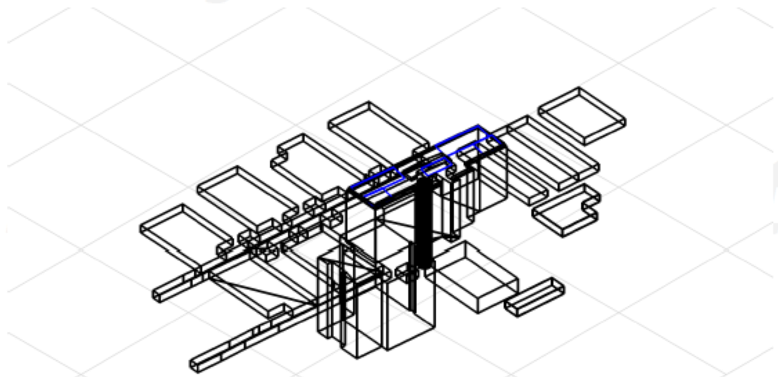
Grid-Connected System: Near shading definition

Project : **Building C's rooftop**

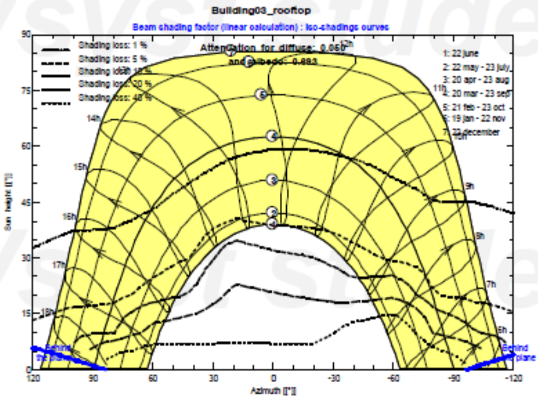
Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	10°	azimuth	-6°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	176	Pnom total	**56.3 kWp**
Inverter	Model	Solargate PV8L070NN	Pnom	57.0 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

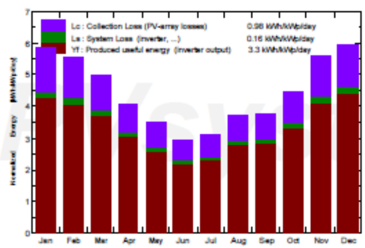
Project : **Building C's rooftop**

Simulation variant : **New simulation variant**

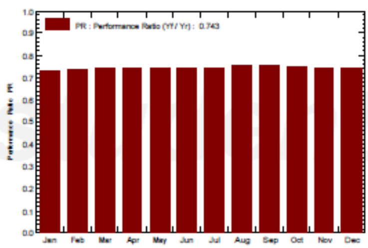
Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	10°	azimuth	-6°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	176	Pnom total	**56.3 kWp**
Inverter	Model	Solargate PV8L070NN	Pnom	57.0 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**67.90 MWh/year**	Specific prod.	1206 kWh/kWp/year
	Performance Ratio PR	74.27 %		

Normalized productions (per installed kWp): Nominal power 56.3 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	181.2	165.5	7.792	7.430	0.728
February	152.9	78.73	23.90	154.9	141.3	6.734	6.416	0.735
March	146.9	75.57	22.00	153.7	139.5	6.755	6.453	0.745
April	113.1	53.88	19.70	122.9	110.5	5.416	5.158	0.745
May	94.9	44.04	17.20	107.8	94.4	4.735	4.507	0.742
June	77.7	39.89	16.60	89.1	77.3	3.928	3.727	0.743
July	84.3	43.92	16.70	95.9	83.6	4.233	4.018	0.744
August	104.8	54.18	17.40	115.6	103.1	5.168	4.916	0.755
September	108.0	62.69	18.80	113.2	102.1	5.050	4.801	0.753
October	135.2	79.69	20.70	137.9	124.8	6.103	5.814	0.749
November	168.3	82.61	22.70	167.6	152.9	7.311	6.983	0.740
December	186.6	90.05	21.30	183.4	167.5	8.041	7.673	0.743
Year	1556.5	787.40	20.12	1623.2	1462.5	71.266	67.896	0.743

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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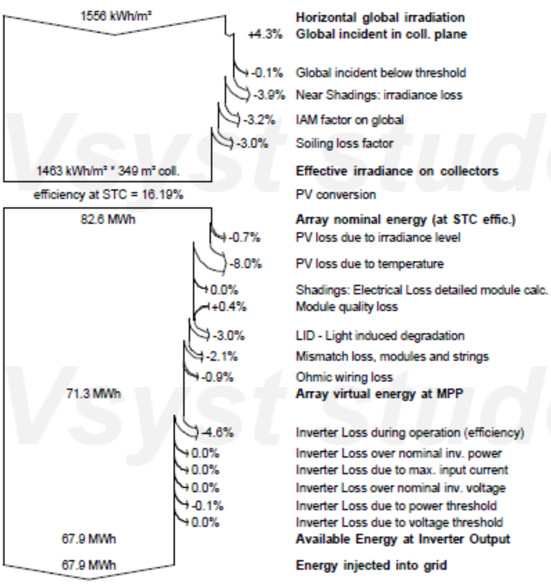
Grid-Connected System: Loss diagram

Project : **Building C's rooftop**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	10°	azimuth	-6°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	176	Pnom total	**56.3 kWp**
Inverter	Model	Solargate PV8L070NN	Pnom	57.0 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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APPENDIX D – Building D's PVsyst reports: rooftop, east façade and west façade, respectively.

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Grid-Connected System: Simulation parameters

Project : **Building D's rooftop**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 21/12/18 15h46

Simulation parameters	System type	**Building system**		
3 orientations	tilts/azimuths	5°/86°, 5°/-94°, 5°/-4°		
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Arrays Characteristics (5 kinds of array defined)

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Sub-array "Sub-array #1"	Orientation	#1	Tilt/Azimuth	5°/86°
Number of PV modules	In series	17 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	68	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**21.76 kWp**	At operating cond.	18.64 kWp (60°C)
Array operating characteristics (50°C)	U mpp	539 V	I mpp	35 A
Sub-array "Sub-array #2"	Orientation	#1	Tilt/Azimuth	5°/86°
Number of PV modules	In series	17 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	68	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**21.76 kWp**	At operating cond.	18.64 kWp (60°C)
Array operating characteristics (50°C)	U mpp	539 V	I mpp	35 A
Sub-array "Sub-array #3"	Orientation	#2	Tilt/Azimuth	5°/-94°
Number of PV modules	In series	17 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	68	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**21.76 kWp**	At operating cond.	18.64 kWp (60°C)
Array operating characteristics (50°C)	U mpp	539 V	I mpp	35 A
Sub-array "Sub-array #4"	Orientation	#2	Tilt/Azimuth	5°/-94°
Number of PV modules	In series	17 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	68	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**21.76 kWp**	At operating cond.	18.64 kWp (60°C)
Array operating characteristics (50°C)	U mpp	539 V	I mpp	35 A
Sub-array "Sub-array #5"	Orientation	#3	Tilt/Azimuth	5°/-4°
Number of PV modules	In series	9 modules	In parallel	2 strings
Total number of PV modules	Nb. modules	18	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**5.76 kWp**	At operating cond.	4935 Wp (60°C)
Array operating characteristics (50°C)	U mpp	285 V	I mpp	17 A
Total Arrays global power	Nominal (STC)	**93 kWp**	Total	290 modules
	Module area	**575 m²**	Cell area	508 m²

Sub-array "Sub-array #1" : Inverter	Model	**TRIO-20.0-TL-OUTD-400**		
Original PVsyst database	Manufacturer	ABB		
Characteristics	Operating Voltage	200-950 V	Unit Nom. Power	22.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	22 kWac
			Pnom ratio	0.99

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Grid-Connected System: Simulation parameters

Sub-array "Sub-array #2" : Inverter	Model	**TRIO-20.0-TL-OUTD-400**		
Original PVsyst database	Manufacturer	ABB		
Characteristics	Operating Voltage	200-950 V	Unit Nom. Power	22.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	22 kWac
			Pnom ratio	0.99
Sub-array "Sub-array #3" : Inverter	Model	**TRIO-20.0-TL-OUTD-400**		
Original PVsyst database	Manufacturer	ABB		
Characteristics	Operating Voltage	200-950 V	Unit Nom. Power	22.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	22 kWac
			Pnom ratio	0.99
Sub-array "Sub-array #4" : Inverter	Model	**TRIO-20.0-TL-OUTD-400**		
Original PVsyst database	Manufacturer	ABB		
Characteristics	Operating Voltage	200-950 V	Unit Nom. Power	22.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	22 kWac
			Pnom ratio	0.99
Sub-array "Sub-array #5" : Inverter	Model	**SolarRiver 6000TL-D**		
Original PVsyst database	Manufacturer	Samil Power		
Characteristics	Operating Voltage	210-500 V	Unit Nom. Power	5.75 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	5.8 kWac
			Pnom ratio	1.00
Total	Nb. of inverters	5	Total Power	94 kWac

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	277 mOhm	Loss Fraction	1.5 % at STC
	Array#2	277 mOhm	Loss Fraction	1.5 % at STC
	Array#3	277 mOhm	Loss Fraction	1.5 % at STC
	Array#4	277 mOhm	Loss Fraction	1.5 % at STC
	Array#5	294 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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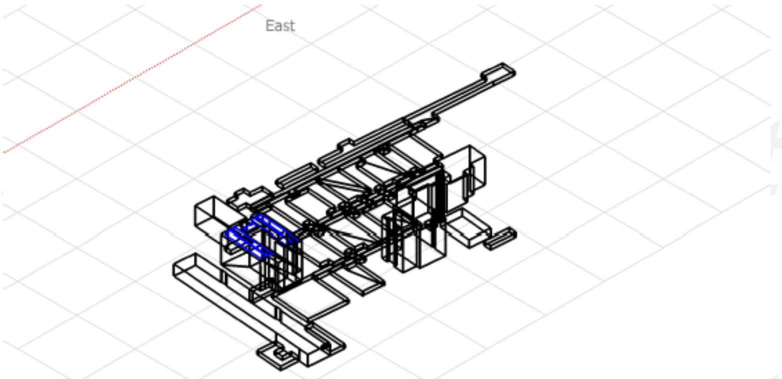
Grid-Connected System: Near shading definition

Project : **Building D's rooftop**

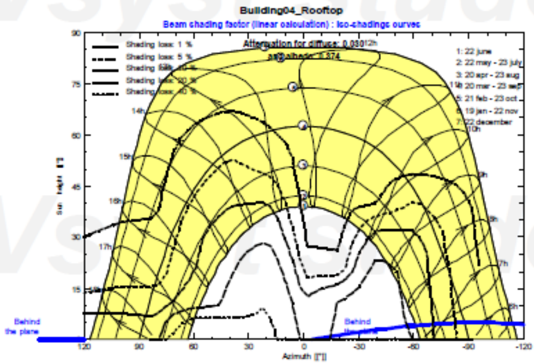
Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	3 orientations	Tilt/Azimuth = 5°/86°, 5°/-94°, 5°/-4°		
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	290	Pnom total	**92.8 kWp**
Inverter	Model	TRIO-20.0-TL-OUTD-400	Pnom	22.00 kW ac
Inverter	Model	SolarRiver 6000TL-D	Pnom	5.75 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**93.8 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

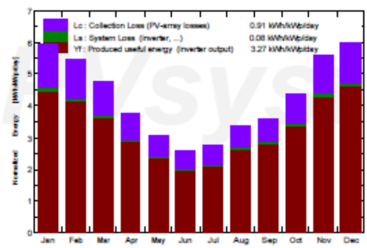
Project : **Building D's rooftop**

Simulation variant : **New simulation variant**

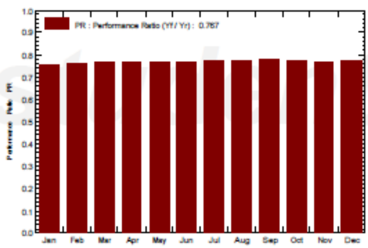
Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	3 orientations	Tilt/Azimuth = 5°/86°, 5°/-94°, 5°/-4°		
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	290	Pnom total	**92.8 kWp**
Inverter	Model	TRIO-20.0-TL-OUTD-400	Pnom	22.00 kW ac
Inverter	Model	SolarRiver 6000TL-D	Pnom	5.75 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**93.8 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**110.9 MWh/year**	Specific prod.	1195 kWh/kWp/year
	Performance Ratio PR	76.74 %		

Normalized productions (per installed kWp): Nominal power 92.8 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	183.6	169.5	13.16	12.85	0.754
February	152.9	78.73	23.90	152.9	140.5	11.07	10.81	0.762
March	146.9	75.57	22.00	147.0	133.3	10.71	10.46	0.767
April	113.1	53.88	19.70	113.3	101.4	8.25	8.06	0.766
May	94.9	44.04	17.20	95.2	83.2	6.93	6.77	0.766
June	77.7	39.89	16.60	78.0	67.7	5.70	5.55	0.767
July	84.3	43.92	16.70	84.6	73.7	6.19	6.03	0.768
August	104.8	54.18	17.40	105.1	93.3	7.76	7.58	0.777
September	108.0	62.69	18.80	108.0	97.6	8.00	7.80	0.778
October	135.2	79.69	20.70	135.1	123.3	9.97	9.73	0.776
November	168.3	82.61	22.70	168.1	155.1	12.23	11.94	0.766
December	186.6	90.05	21.30	186.3	172.2	13.61	13.30	0.769
Year	1556.5	787.40	20.12	1557.2	1410.8	113.58	110.89	0.767

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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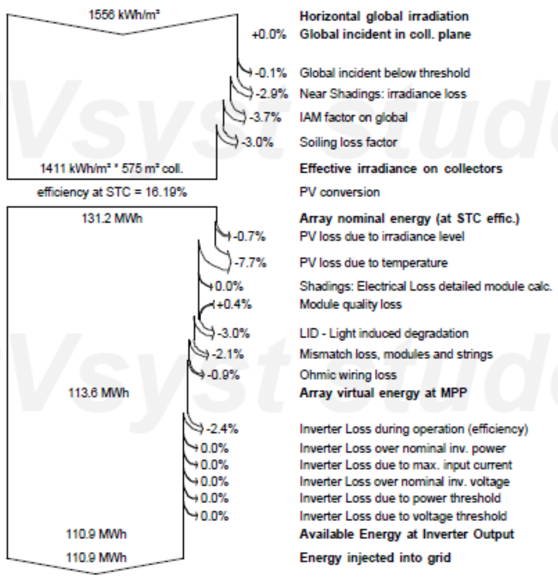
Grid-Connected System: Loss diagram

Project : **Building D's rooftop**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	3 orientations	Tilt/Azimuth = 5°/86°, 5°/-94°, 5°/-4°		
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	290	Pnom total	**92.8 kWp**
Inverter	Model	TRIO-20.0-TL-OUTD-400	Pnom	22.00 kW ac
Inverter	Model	SolarRiver 6000TL-D	Pnom	5.75 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**93.8 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building D's east façade**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 17h59

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	90°	Azimuth	-94°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Array Characteristics

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	9 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	36	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**11.52 kWp**	At operating cond.	9.87 kWp (60°C)
Array operating characteristics (50°C)	U mpp	285 V	I mpp	35 A
Total area	Module area	**71.3 m²**	Cell area	63.1 m²

Inverter	Model	**IG Plus 150 V-3**		
Original PVsyst database	Manufacturer	Fronius International		
Characteristics	Operating Voltage	230-500 V	Unit Nom. Power	12.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	12.0 kWac
			Pnom ratio	0.96

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	147 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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Grid-Connected System: Near shading definition

Project : **Building D's east façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-94°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	36	Pnom total	**11.52 kWp**
Inverter	Model	IG Plus 150 V-3	Pnom	12.00 kW ac
User's needs	Unlimited load (grid)			

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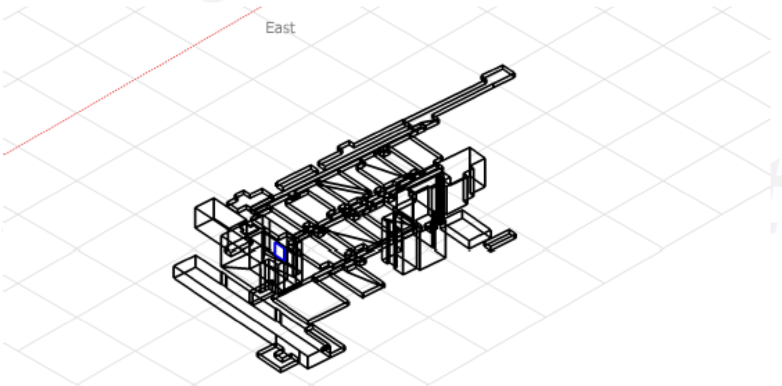
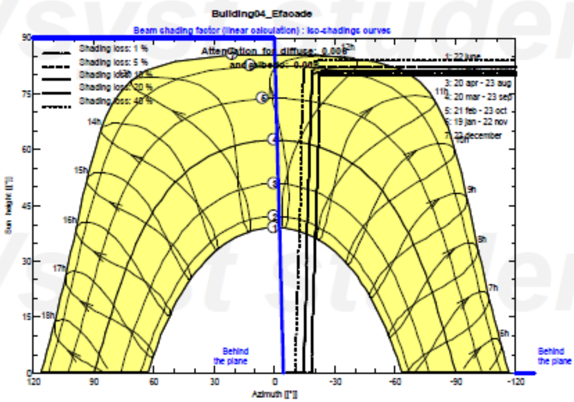
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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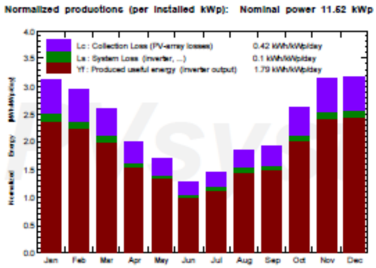
Grid-Connected System: Main results

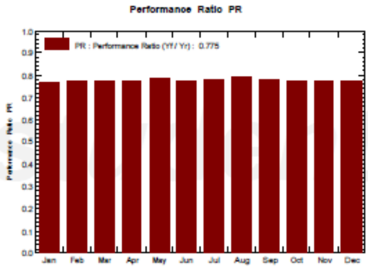
Project : **Building D's east façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-94°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	36	Pnom total	**11.52 kWp**
Inverter	Model	IG Plus 150 V-3	Pnom	12.00 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**7.53 MWh/year**	Specific prod.	653 kWh/kWp/year
	Performance Ratio PR	77.48 %		





New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	96.59	90.00	0.896	0.850	0.764
February	152.9	78.73	23.90	82.37	76.54	0.768	0.729	0.768
March	146.9	75.57	22.00	80.61	74.87	0.757	0.719	0.774
April	113.1	53.88	19.70	59.76	55.35	0.565	0.535	0.777
May	94.9	44.04	17.20	52.72	48.49	0.504	0.476	0.784
June	77.7	39.89	16.60	38.42	35.02	0.364	0.343	0.775
July	84.3	43.92	16.70	44.85	41.01	0.426	0.402	0.779
August	104.8	54.18	17.40	57.15	52.68	0.549	0.520	0.790
September	108.0	62.69	18.80	57.73	53.45	0.549	0.519	0.781
October	135.2	79.69	20.70	80.94	75.27	0.764	0.725	0.777
November	168.3	82.61	22.70	94.40	87.72	0.879	0.836	0.768
December	186.6	90.05	21.30	97.91	90.99	0.920	0.874	0.775
Year	1556.5	787.40	20.12	843.46	781.39	7.942	7.528	0.775

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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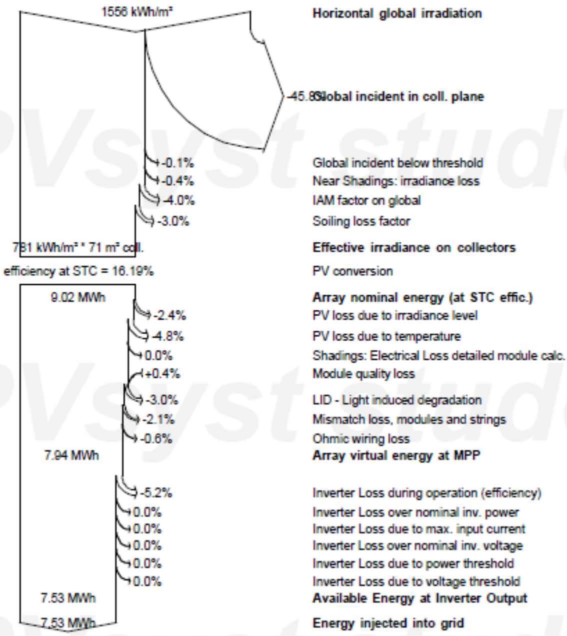
Grid-Connected System: Loss diagram

Project : **Building D's east façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-94°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	36	Pnom total	**11.52 kWp**
Inverter	Model	IG Plus 150 V-3	Pnom	12.00 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building D's west façade**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 18h02

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	90°	Azimuth	86°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Array Characteristics

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	9 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	36	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**11.52 kWp**	At operating cond.	9.87 kWp (60°C)
Array operating characteristics (50°C)	U mpp	285 V	I mpp	35 A
Total area	Module area	**71.3 m²**	Cell area	63.1 m²

Inverter	Model	**IG Plus 150 V-3**		
Original PVsyst database	Manufacturer	Fronius International		
Characteristics	Operating Voltage	230-500 V	Unit Nom. Power	12.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	12.0 kWac
			Pnom ratio	0.96

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	147 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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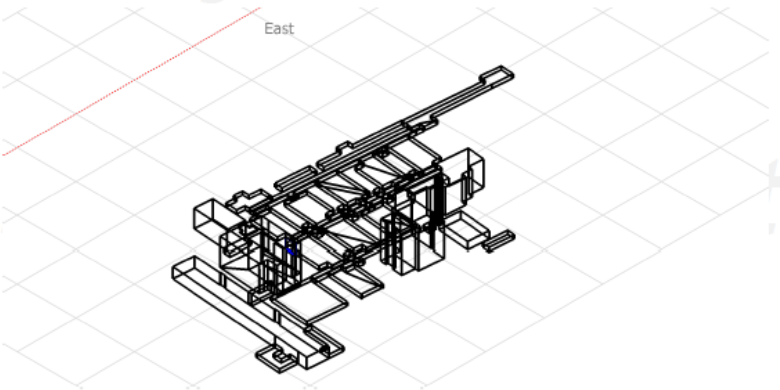
Grid-Connected System: Near shading definition

Project : **Building D's west façade**

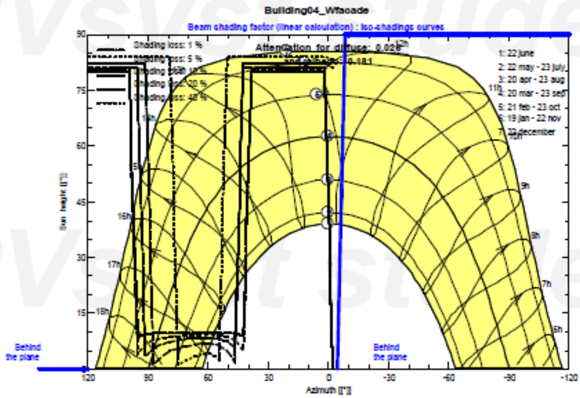
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	86°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	36	Pnom total	**11.52 kWp**
Inverter	Model	IG Plus 150 V-3	Pnom	12.00 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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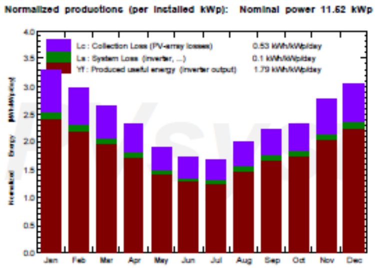
Grid-Connected System: Main results

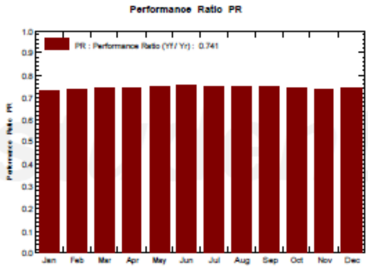
Project : **Building D's west façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**			
Near Shadings	Detailed electrical calculation	(acc. to module layout)			
PV Field Orientation	tilt	90°		azimuth	86°
PV modules	Model	BYD-320-P6C-36-DG		Pnom	320 Wp
PV Array	Nb. of modules	36		Pnom total	**11.52 kWp**
Inverter	Model	IG Plus 150 V-3		Pnom	12.00 kW ac
User's needs	Unlimited load (grid)				

Main simulation results					
System Production	**Produced Energy**	**7.51 MWh/year**		Specific prod.	652 kWh/kWp/year
	Performance Ratio PR	74.12 %			





New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	102.7	92.20	0.908	0.862	0.729
February	152.9	78.73	23.90	83.6	74.88	0.745	0.706	0.734
March	146.9	75.57	22.00	82.3	73.66	0.739	0.702	0.740
April	113.1	53.88	19.70	70.1	62.98	0.631	0.598	0.741
May	94.9	44.04	17.20	58.6	52.53	0.535	0.506	0.750
June	77.7	39.89	16.60	51.5	46.06	0.474	0.448	0.755
July	84.3	43.92	16.70	51.6	45.92	0.472	0.446	0.751
August	104.8	54.18	17.40	61.5	54.77	0.560	0.530	0.749
September	108.0	62.69	18.80	67.1	60.33	0.611	0.578	0.748
October	135.2	79.69	20.70	72.5	64.82	0.657	0.622	0.744
November	168.3	82.61	22.70	83.4	74.60	0.744	0.706	0.734
December	186.6	90.05	21.30	94.3	84.03	0.846	0.803	0.739
Year	1556.5	787.40	20.12	879.3	786.79	7.921	7.508	0.741

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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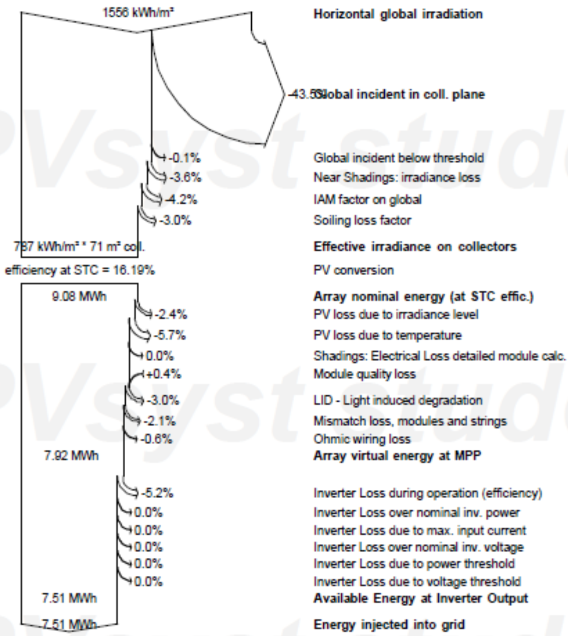
Grid-Connected System: Loss diagram

Project : **Building D’s west façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	86°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	36	Pnom total	**11.52 kWp**
Inverter	Model	IG Plus 150 V-3	Pnom	12.00 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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APPENDIX E – Building E's PVsyst reports: rooftop, north façade and west façade, respectively.

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Grid-Connected System: Simulation parameters

Project : **Building E's rooftop**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 21/12/18 14h07

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	27°	Azimuth	-5°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Array Characteristics

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	13 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	52	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**16.64 kWp**	At operating cond.	14.26 kWp (60°C)
Array operating characteristics (50°C)	U mpp	412 V	I mpp	35 A
Total area	Module area	**103 m²**	Cell area	91.1 m²
Inverter	Model	**AS-IC01-15000-2 (15kw,three-phase with 2 MPPT)**		
Original PVsyst database	Manufacturer	AEG Industrial Solar GmbH		
Characteristics	Operating Voltage	180-800 V	Unit Nom. Power	15.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	15.0 kWac
			Pnom ratio	1.11

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	212 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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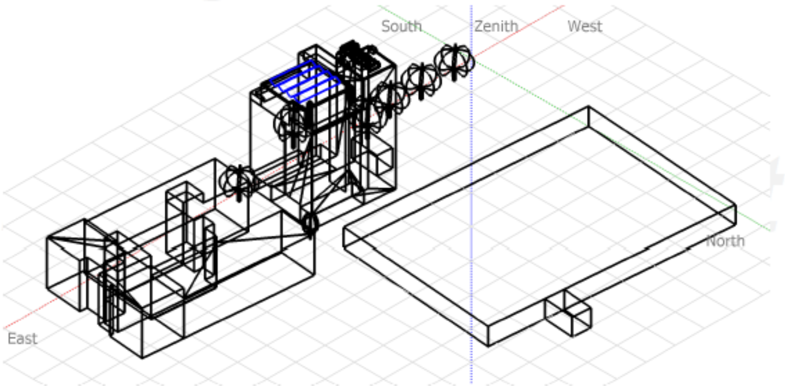
Grid-Connected System: Near shading definition

Project : **Building E's rooftop**

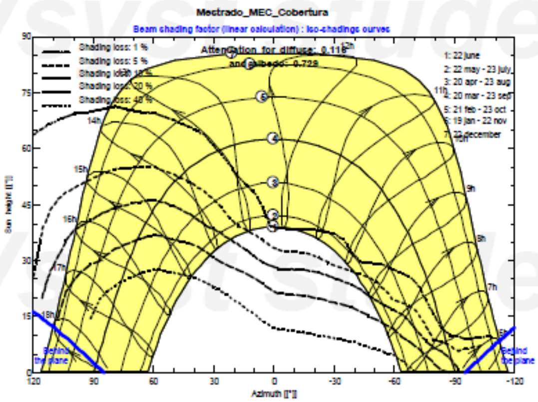
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	27°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	52	Pnom total	**16.64 kWp**
Inverter	AS-IC01-15000-2 (15kw,three-phase with 2 MPPT)		Pnom	15.00 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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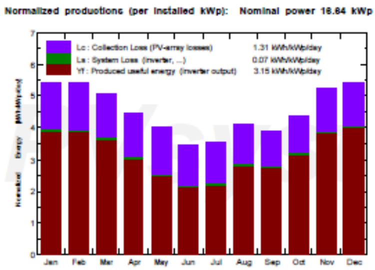
Grid-Connected System: Main results

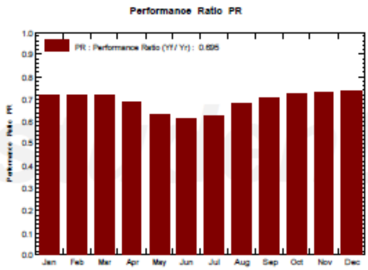
Project : **Building E's rooftop**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	27°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	52	Pnom total	**16.64 kWp**
Inverter	AS-IC01-15000-2 (15kw,three-phase with 2 MPPT)		Pnom	15.00 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**19.11 MWh/year**	Specific prod.	1149 kWh/kWp/year
	Performance Ratio PR	69.46 %		





New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	167.9	145.7	2.052	2.007	0.719
February	152.9	78.73	23.90	150.5	129.9	1.838	1.797	0.718
March	146.9	75.57	22.00	157.4	135.1	1.906	1.866	0.712
April	113.1	53.88	19.70	133.0	112.2	1.548	1.514	0.684
May	94.9	44.04	17.20	124.0	102.2	1.325	1.294	0.627
June	77.7	39.89	16.60	103.7	83.9	1.091	1.063	0.616
July	84.3	43.92	16.70	110.6	90.8	1.175	1.145	0.622
August	104.8	54.18	17.40	127.9	107.1	1.484	1.449	0.681
September	108.0	62.69	18.80	116.5	98.4	1.403	1.369	0.706
October	135.2	79.69	20.70	135.6	116.1	1.674	1.636	0.725
November	168.3	82.61	22.70	157.6	136.4	1.951	1.909	0.728
December	186.6	90.05	21.30	168.8	146.3	2.110	2.064	0.735
Year	1556.5	787.40	20.12	1653.6	1404.1	19.556	19.113	0.695

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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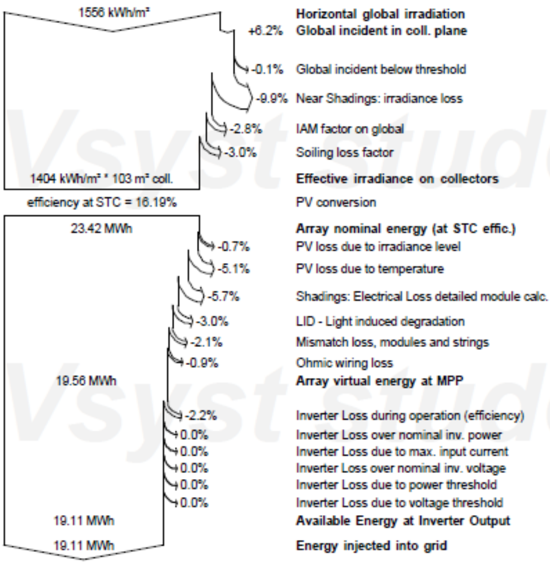
Grid-Connected System: Loss diagram

Project : **Building E's rooftop**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	27°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	52	Pnom total	**16.64 kWp**
Inverter	AS-IC01-15000-2 (15kw,three-phase with 2 MPPT)		Pnom	15.00 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building E's north façade**

Geographical Site	**Florianópolis_Atlas2017**			Country	**Brazil**
Situation		Latitude	-27.59° S	Longitude	-48.55° W
Time defined as		Legal Time	Time zone UT-3	Altitude	3 m
		Albedo	0.20		
Meteo data:		**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 23/10/18 14h57

Simulation parameters		System type	**Sheds on a building**		
Collector Plane Orientation		Tilt	90°	Azimuth	-5°
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon		Free Horizon			
Near Shadings		Detailed electrical calculation	(acc. to module layout)		
PV Array Characteristics					
PV module	Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition		Manufacturer	BYD		
Number of PV modules		In series	16 modules	In parallel	8 strings
Total number of PV modules		Nb. modules	128	Unit Nom. Power	320 Wp
Array global power		Nominal (STC)	**41.0 kWp**	At operating cond.	35.1 kWp (60°C)
Array operating characteristics (50°C)		U mpp	507 V	I mpp	69 A
Total area		Module area	**254 m²**	Cell area	224 m²
Inverter		Model	**FreeSun FS0040 LVT**		
Original PVsyst database		Manufacturer	Power Electronics		
Characteristics		Operating Voltage	450-820 V	Unit Nom. Power	40.0 kWac
Inverter pack		Nb. of inverters	1 units	Total Power	40 kWac
				Pnom ratio	1.02
PV Array loss factors					
Array Soiling Losses				Loss Fraction	3.0 %
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	130 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation				Loss Fraction	3.0 %
Module Quality Loss				Loss Fraction	0.0 %
Module Mismatch Losses				Loss Fraction	2.0 % at MPP
Strings Mismatch loss				Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :		Unlimited load (grid)			

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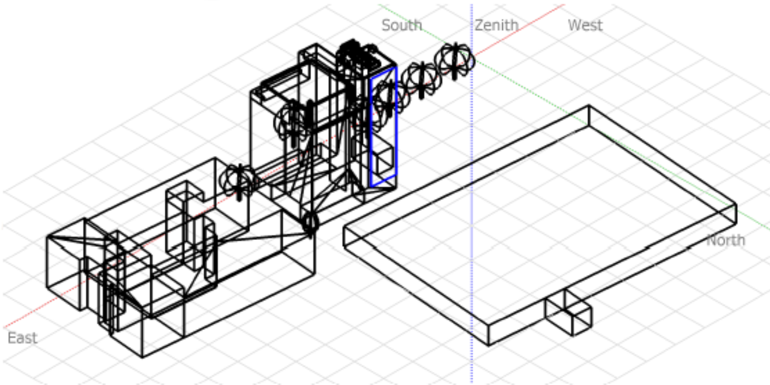
Grid-Connected System: Near shading definition

Project : **Building E's north façade**

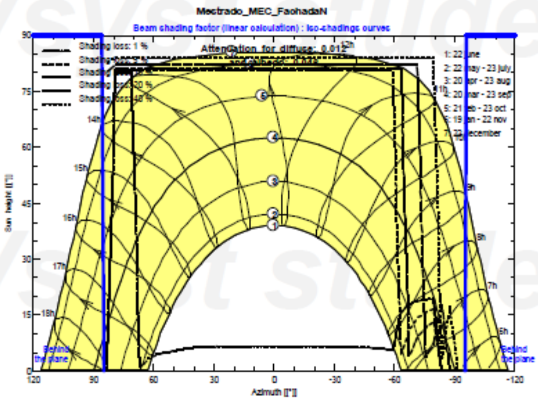
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	128	Pnom total	**41.0 kWp**
Inverter	Model	FreeSun FS0040 LVT	Pnom	40.0 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

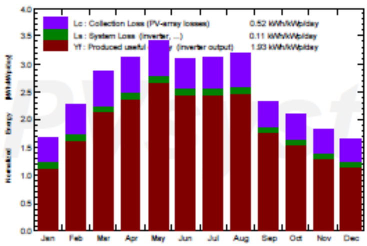
Project : **Building E's north façade**

Simulation variant : **New simulation variant**

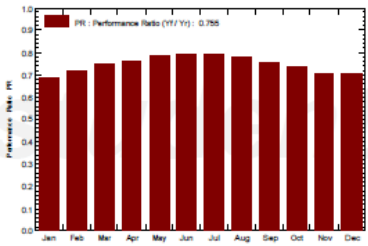
Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	128	Pnom total	**41.0 kWp**
Inverter	Model	FreeSun FS0040 LVT	Pnom	40.0 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	Produced Energy	**28.85 MWh/year**	Specific prod.	704 kWh/kWp/year
	Performance Ratio PR	75.47 %		

Normalized productions (per installed kWp): Nominal power 41.0 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	51.9	44.73	1.591	1.460	0.686
February	152.9	78.73	23.90	63.6	55.62	2.001	1.876	0.720
March	146.9	75.57	22.00	88.9	79.31	2.865	2.722	0.748
April	113.1	53.88	19.70	93.5	85.08	3.061	2.913	0.761
May	94.9	44.04	17.20	106.1	98.50	3.564	3.402	0.783
June	77.7	39.89	16.60	93.1	86.70	3.162	3.019	0.792
July	84.3	43.92	16.70	96.7	89.87	3.275	3.127	0.790
August	104.8	54.18	17.40	98.4	90.46	3.295	3.141	0.779
September	108.0	62.69	18.80	70.1	62.97	2.299	2.169	0.755
October	135.2	79.69	20.70	65.0	57.40	2.088	1.956	0.735
November	168.3	82.61	22.70	55.1	47.50	1.714	1.595	0.707
December	186.6	90.05	21.30	51.1	44.24	1.598	1.473	0.704
Year	1556.5	787.40	20.12	933.3	842.38	30.514	28.853	0.755

Legends:			
GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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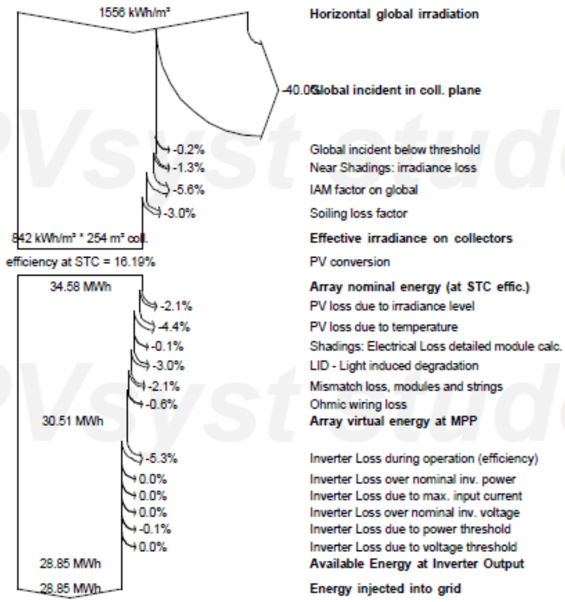
Grid-Connected System: Loss diagram

Project : **Building E's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-5°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	128	Pnom total	**41.0 kWp**
Inverter	Model	FreeSun FS0040 LVT	Pnom	40.0 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building E's west façade**

Geographical Site	**Florianópolis_Atlas2017**			Country	**Brazil**
Situation		Latitude	-27.59° S	Longitude	-48.55° W
Time defined as		Legal Time	Time zone UT-3	Altitude	3 m
		Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**		AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 14h48

Simulation parameters		System type	**Sheds on a building**		
Collector Plane Orientation		Tilt	90°	Azimuth	85°
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon		Free Horizon			
Near Shadings		Detailed electrical calculation	(acc. to module layout)		
PV Array Characteristics					
PV module	Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition		Manufacturer	BYD		
Number of PV modules		In series	16 modules	In parallel	7 strings
Total number of PV modules		Nb. modules	112	Unit Nom. Power	320 Wp
Array global power		Nominal (STC)	**35.8 kWp**	At operating cond.	30.7 kWp (60°C)
Array operating characteristics (50°C)		U mpp	507 V	I mpp	61 A
Total area		Module area	**222 m²**	Cell area	196 m²
Inverter		Model	**FreeSun FS0035 LVT**		
Original PVsyst database		Manufacturer	Power Electronics		
Characteristics		Operating Voltage	450-820 V	Unit Nom. Power	35.0 kWac
Inverter pack		Nb. of inverters	1 units	Total Power	35 kWac
				Pnom ratio	1.02
PV Array loss factors					
Array Soiling Losses				Loss Fraction	3.0 %
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	149 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation				Loss Fraction	3.0 %
Module Quality Loss				Loss Fraction	-0.4 %
Module Mismatch Losses				Loss Fraction	2.0 % at MPP
Strings Mismatch loss				Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :		Unlimited load (grid)			

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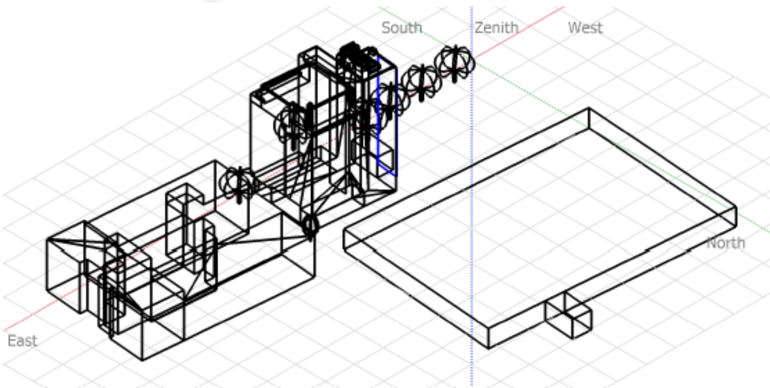
Grid-Connected System: Near shading definition

Project : **Building E's west façade**

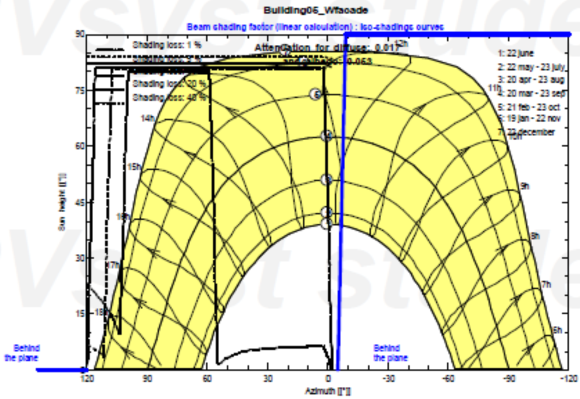
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	85°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	112	Pnom total	**35.8 kWp**
Inverter	Model	FreeSun FS0035 LVT	Pnom	35.0 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

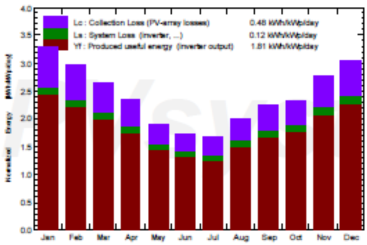
Project : **Building E's west façade**

Simulation variant : **New simulation variant**

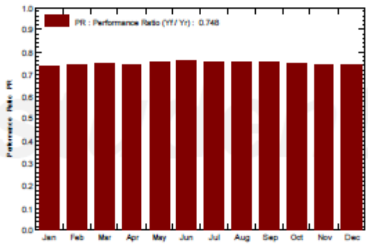
Main system parameters	System type	**Sheds on a building**			
Near Shadings	Detailed electrical calculation	(acc. to module layout)			
PV Field Orientation	tilt	90°	azimuth	85°	
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp	
PV Array	Nb. of modules	112	Pnom total	**35.8 kWp**	
Inverter	Model	FreeSun FS0035 LVT	Pnom	35.0 kW ac	
User's needs	Unlimited load (grid)				

Main simulation results				
System Production	**Produced Energy**	**23.66 MWh/year**	Specific prod.	660 kWh/kWp/year
	Performance Ratio PR	74.84 %		

Normalized productions (per installed kWp): Nominal power 35.8 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	102.6	94.12	2.866	2.694	0.733
February	152.9	78.73	23.90	83.7	76.77	2.371	2.228	0.743
March	146.9	75.57	22.00	82.6	75.68	2.363	2.221	0.750
April	113.1	53.88	19.70	70.5	64.76	2.019	1.889	0.747
May	94.9	44.04	17.20	59.1	54.14	1.717	1.596	0.753
June	77.7	39.89	16.60	52.0	47.51	1.521	1.416	0.760
July	84.3	43.92	16.70	52.1	47.41	1.517	1.411	0.756
August	104.8	54.18	17.40	61.9	56.51	1.800	1.678	0.756
September	108.0	62.69	18.80	67.3	61.92	1.950	1.820	0.754
October	135.2	79.69	20.70	72.6	66.56	2.098	1.957	0.752
November	168.3	82.61	22.70	83.4	76.45	2.373	2.225	0.744
December	186.6	90.05	21.30	94.2	86.01	2.685	2.523	0.747
Year	1556.5	787.40	20.12	882.0	807.85	25.281	23.656	0.748

Legends:			
GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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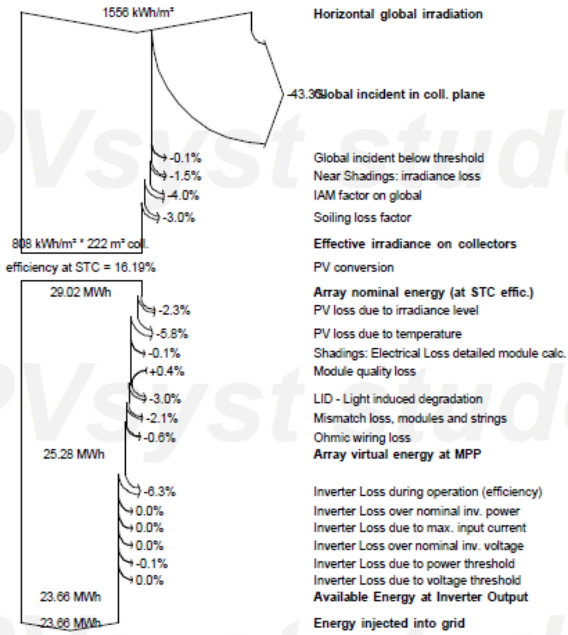
Grid-Connected System: Loss diagram

Project : **Building E's west façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	85°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	112	Pnom total	**35.8 kWp**
Inverter	Model	FreeSun FS0035 LVT	Pnom	35.0 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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APPENDIX F – Building F's PVsyst reports: rooftop and north façade, respectively.

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Grid-Connected System: Simulation parameters

Project :	**Building F's rooftop**			
Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant :	**New simulation variant**			
	Simulation date	20/12/18 17h33		

Simulation parameters	System type	**Building system**		
Collector Plane Orientation	Tilt	10°	Azimuth	-4°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Array Characteristics				
PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	15 modules	In parallel	30 strings
Total number of PV modules	Nb. modules	450	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**144 kWp**	At operating cond.	123 kWp (60°C)
Array operating characteristics (50°C)	U mpp	476 V	I mpp	259 A
Total area	Module area	**891 m²**	Cell area	789 m²
Inverter	Model	**SUNSYS P66**		
Original PVsyst database	Manufacturer	Socomec		
Characteristics	Operating Voltage	350-850 V	Unit Nom. Power	66.0 kWac
Inverter pack	Nb. of inverters	4 * MPPT 50 %	Total Power	132 kWac
			Pnom ratio	1.09
PV Array loss factors				
Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	33 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :	Unlimited load (grid)			

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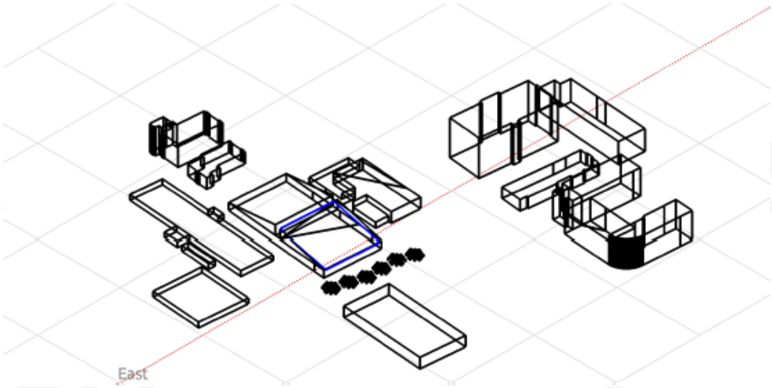
Grid-Connected System: Near shading definition

Project : **Building F's rooftop**

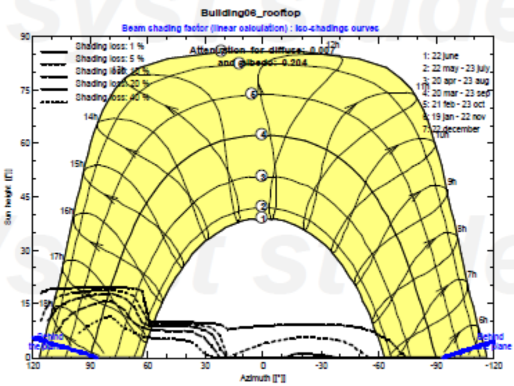
Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	10°	azimuth	-4°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	450	Pnom total	**144 kWp**
Inverter	Model	SUNSYS P66	Pnom	66.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**132 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

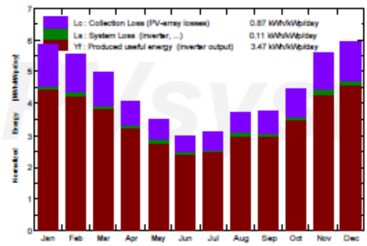
Project : **Building F's rooftop**

Simulation variant : **New simulation variant**

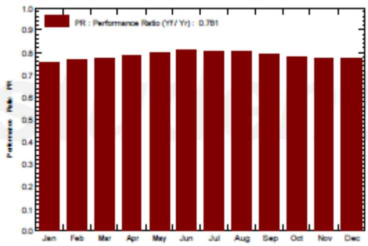
Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	10°	azimuth	-4°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	450	Pnom total	**144 kWp**
Inverter	Model	SUNSYS P66	Pnom	66.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**132 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**182.6 MWh/year**	Specific prod.	1268 kWh/kWp/year
	Performance Ratio PR	78.12 %		

Normalized productions (per installed kWp): Nominal power 144 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	181.2	169.2	20.34	19.75	0.757
February	152.9	78.73	23.90	154.9	144.8	17.62	17.10	0.766
March	146.9	75.57	22.00	153.7	143.0	17.67	17.16	0.775
April	113.1	53.88	19.70	122.9	114.6	14.33	13.91	0.786
May	94.9	44.04	17.20	107.9	100.3	12.84	12.46	0.802
June	77.7	39.89	16.60	89.2	82.7	10.73	10.40	0.810
July	84.3	43.92	16.70	96.0	89.1	11.51	11.16	0.808
August	104.8	54.18	17.40	115.6	107.8	13.79	13.38	0.803
September	108.0	62.69	18.80	113.3	105.1	13.28	12.88	0.790
October	135.2	79.69	20.70	137.8	128.1	15.99	15.52	0.782
November	168.3	82.61	22.70	167.5	156.4	19.10	18.54	0.768
December	186.6	90.05	21.30	183.4	171.4	21.01	20.39	0.772
Year	1556.5	787.40	20.12	1623.5	1512.5	188.22	182.63	0.781

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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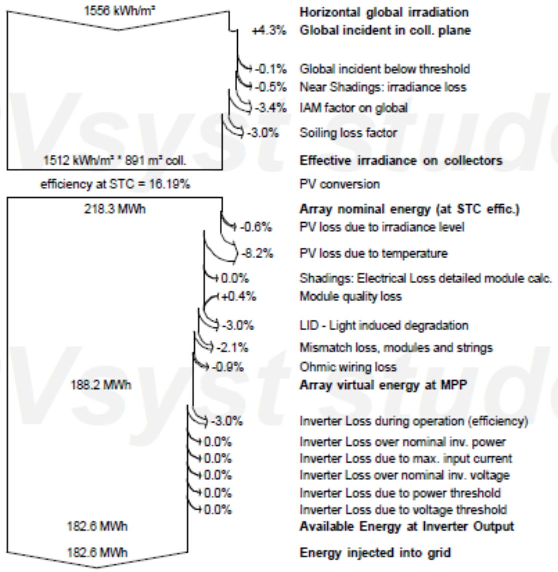
Grid-Connected System: Loss diagram

Project : **Building F's rooftop**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Building system**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	10°	azimuth	-4°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	450	Pnom total	**144 kWp**
Inverter	Model	SUNSYS P66	Pnom	66.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**132 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Building F's north façade**

Geographical Site	**Florianópolis_Atlas2017**		Country	**Brazil**
Situation	Latitude	-27.59° S	Longitude	-48.55° W
Time defined as	Legal Time	Time zone UT-3	Altitude	3 m
	Albedo	0.20		
Meteo data:	**Florianópolis_Atlas2017**	AtlasBrasileirodeEnergiaSolar2017 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 20/12/18 17h48

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	90°	Azimuth	-4°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Detailed electrical calculation	(acc. to module layout)		

PV Array Characteristics

PV module Si-poly	Model	**BYD-320-P6C-36-DG**		
Custom parameters definition	Manufacturer	BYD		
Number of PV modules	In series	15 modules	In parallel	2 strings
Total number of PV modules	Nb. modules	30	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**9.60 kWp**	At operating cond.	8.23 kWp (60°C)
Array operating characteristics (50°C)	U mpp	476 V	I mpp	17 A
Total area	Module area	**59.4 m²**	Cell area	52.6 m²

Inverter	Model	**FLX Pro 9**		
Original PVsyst database	Manufacturer	Danfoss		
Characteristics	Operating Voltage	220-800 V	Unit Nom. Power	9.00 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	9.0 kWac
			Pnom ratio	1.07

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	489 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	3.0 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

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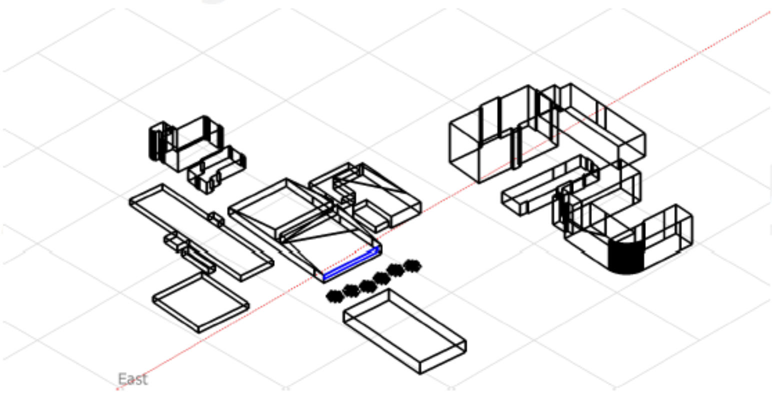
Grid-Connected System: Near shading definition

Project : **Building F's north façade**

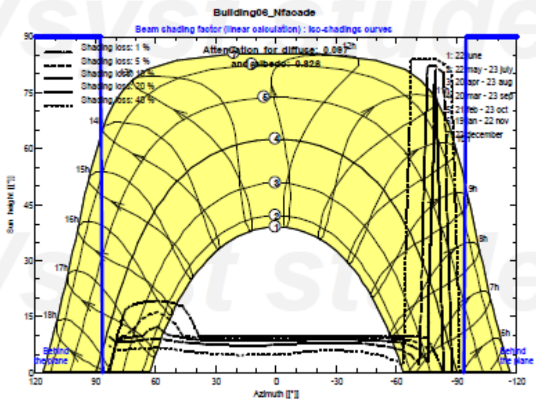
Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-4°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	30	Pnom total	**9.60 kWp**
Inverter	Model	FLX Pro 9	Pnom	9.00 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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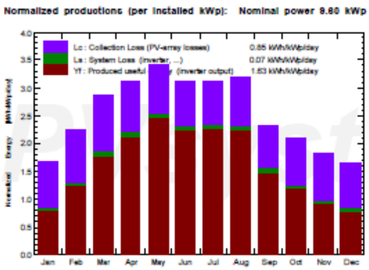
Grid-Connected System: Main results

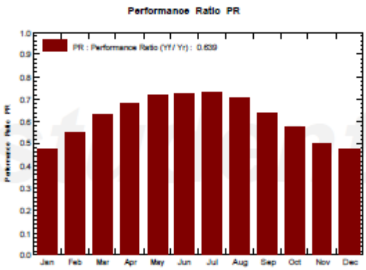
Project : **Building F's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-4°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	30	Pnom total	**9.60 kWp**
Inverter	Model	FLX Pro 9	Pnom	9.00 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**5.72 MWh/year**	Specific prod.	596 kWh/kWp/year
	Performance Ratio PR	63.93 %		





New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	183.8	82.15	24.70	51.6	31.09	0.255	0.234	0.473
February	152.9	78.73	23.90	63.3	41.91	0.353	0.333	0.548
March	146.9	75.57	22.00	88.8	65.29	0.557	0.535	0.627
April	113.1	53.88	19.70	93.7	74.29	0.634	0.612	0.680
May	94.9	44.04	17.20	106.2	88.89	0.759	0.736	0.722
June	77.7	39.89	16.60	93.4	78.52	0.669	0.648	0.723
July	84.3	43.92	16.70	96.8	81.08	0.698	0.676	0.728
August	104.8	54.18	17.40	98.5	79.89	0.690	0.667	0.706
September	108.0	62.69	18.80	70.3	52.40	0.451	0.430	0.638
October	135.2	79.69	20.70	64.7	44.36	0.377	0.356	0.574
November	168.3	82.61	22.70	54.5	33.67	0.281	0.262	0.500
December	186.6	90.05	21.30	50.8	30.52	0.254	0.233	0.478
Year	1556.5	787.40	20.12	932.6	701.91	5.978	5.724	0.639

Legends:			
GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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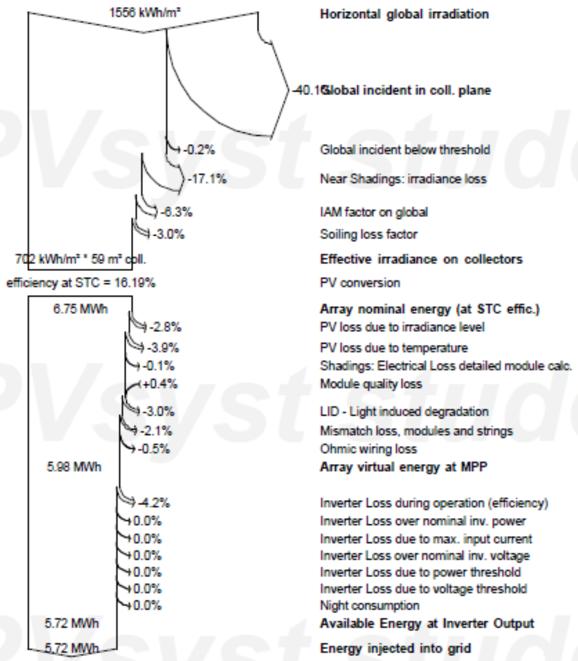
Grid-Connected System: Loss diagram

Project : **Building F's north façade**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Detailed electrical calculation	(acc. to module layout)		
PV Field Orientation	tilt	90°	azimuth	-4°
PV modules	Model	BYD-320-P6C-36-DG	Pnom	320 Wp
PV Array	Nb. of modules	30	Pnom total	**9.60 kWp**
Inverter	Model	FLX Pro 9	Pnom	9.00 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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ATTACHMENT 1 – Adopted PV module's datasheet: BYD Series P6D-36 4BB, 320 Wp.

Série BYD P6D-36 4BB

310W 315W 320W 325W 330W 335W 340W

A virada de jogo: BYD 430

4 - Vida útil de até 40 anos.
3 - Degradação anual mínima de 0,3%
0 - Livre de PID e microfissuras

2ª Geração dos módulos BYD Double Glass

Maior rentabilidade
- Degradação anual mínima de 0,3%
- Maior retorno de investimento
- Fácil instalação
- Maior tensão máxima na "String"
- Baixo custo para o sistema

Maior durabilidade
- Design exclusivo de vidro duplo que elimina as microfissuras no material
- Até 40 anos de vida útil

Maior eficiência
- Sem perda de UV
- Maior potência útil

Maior confiabilidade
- Livre de PID e microfissuras
- Sem uso de EVA

18.3% Eficiência celular média de 18,3%
Excelente desempenho óptico

0~5W Tolerância positiva (+5W)
Confiabilidade na potência de saída

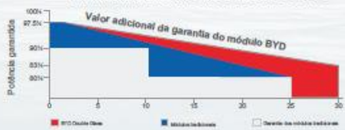
12 Years Garantia do produto: 12 anos
Garantia linear: 30 anos

Grid Sistemas residenciais
Sistemas comerciais On/Off-grid
Usinas solares

3rd Teste de peso TUV 5400Pa
Teste de resistência mecânica CSA 5400 Pa

IEC 61215 (Ed. 2015), IEC 61730, UL1703
ISO9001:2008, ISO14001:2004

Garantia linear dos módulos BYD P6D-36 4BB



Processo de produção


Análise das células


Montagem dos módulos


Sistema fotovoltaico

BYD Energy do Brasil

A BYD Energy do Brasil, inaugurada na cidade de Campinas em fevereiro de 2017, traz ao mercado brasileiro a última tecnologia em matéria de módulos fotovoltaicos: o painel Double Glass. A fábrica é mais um passo da empresa chinesa em direção aos seus 3 Sonhos Verdes: geração de energia renovável, armazenamento de energia e mobilidade elétrica. Junto com a unidade de chassis de ônibus elétricos, a BYD concretizou mais de R$ 600 milhões em investimentos no Brasil.

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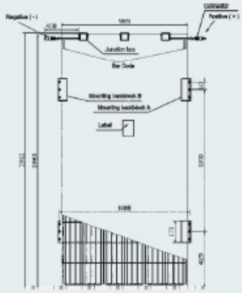
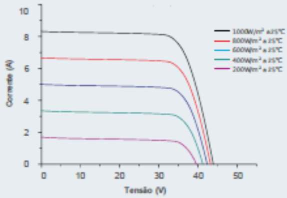
Série BYD P6D-36 4BB

Build Your Dreams

310W 315W 320W 325W 330W 335W 340W





Ficha técnica	
Célula	Silício policristalino 156 mm x 156 mm
Nº de células	72 (6 x 12) unidades
Dimensões do módulo	1961 mm x 985 mm x 29 mm
Peso	32,9 kg
Vidro frontal	Vidro temperado de 3,2 mm com revestimento anti-reflexo
Caixa de junção	ZH-011B-5, TS03-13, TS03-13B
Conector	IP67
Diodos Bypass	3 unidades
Tipo de conexão	PV-ZH202, TL-CABLE01S, TS01
Área de seção do cabo	4 mm²
Comprimento do cabo	2 x 400 mm

Coeficientes de temperatura	
Temperatura de Operação Normal (NOCT)	43ºC ± 2ºC
Coeficiente de temperatura da CC	0,066%/ºC
Coeficiente de temperatura da CA	-0,30%/ºC
Coeficiente de temperatura do pico de potência	-0,37%/ºC

Informações de lote	
Contelner	40' HC
Módulos / Palete	31
Palete / Contelner	22
Módulos / Contelner	682

Especificações elétricas

STC

Módulo / Item	BYD 310P6D-36	BYD 315P6D-36	BYD 320P6D-36	BYD 325P6D-36	BYD 330P6D-36	BYD 335P6D-36	BYD 340P6D-36
Tensão de circuito aberto (VOC)	45,79V	46,09V	46,39V	46,69V	46,98V	47,28V	47,58V
Tensão no pico de potência (Vmáx)	36,38V	36,58V	36,78V	36,98V	37,16V	37,35V	37,53V
Corrente de curto-circuito (Isc)	8,99A	9,07A	9,15A	9,23A	9,31A	9,39A	9,47A
Corrente no pico de potência (Imáx)	8,52A	8,61A	8,70A	8,79A	8,88A	8,97A	9,06A
Potência máxima (Pmáx)	310 Wp	315 Wp	320 Wp	325 Wp	330 Wp	335 Wp	340 Wp
Eficiência do módulo	16,0%	16,3%	16,6%	16,8%	17,1%	17,3%	17,6%
Temperatura de operação				-40℃~85℃			
Limite da corrente inversa				15 A			
Tensão máxima do sistema				1000VDC/1500VDC			
Tolerância da potência				0~5 W			
Classe de aplicação				A			

STC: Irradiância 1000W/m², temperatura de operação 25℃, AM=1,5 Redução média de eficiência: 5% por 200W/m²

NOCT

Módulo / Item	BYD 310P6D-36	BYD 315P6D-36	BYD 320P6D-36	BYD 325P6D-36	BYD 330P6D-36	BYD 335P6D-36	BYD 340P6D-36
Tensão de circuito aberto (VOC)	42,8V	43,0V	43,3V	43,5V	43,8V	44,1V	44,0V
Tensão no pico de potência (Vmáx)	34,4V	34,6V	34,9V	35,1V	35,3V	35,6V	35,7V
Corrente de curto-circuito (Isc)	7,28A	7,34A	7,40A	7,47A	7,54A	7,60A	7,67A
Corrente no pico de potência (Imáx)	6,74A	6,80A	6,86A	6,93A	6,99A	7,05A	7,14A
Potência máxima (Pmáx)	231,8Wp	235,3Wp	239,3Wp	243,2Wp	247,1Wp	251,1Wp	254,8Wp

NOCT: Irradiância 800W/m², temperatura de operação 20°C, velocidade de vento 1m/s.

Versão 1.1/2017

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