Evaluation of Adaptive Facades within Context of Sustainable Building in Northern Cyprus

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Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Architecture

Eastern Mediterranean University
February 2022
Gazimağusa, North Cyprus

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ABSTRACT

The demands for sustainability are effectively growing and increasing the advancement. People in the field (builders, architects, engineers, and the construction sector) are trying to keep up with the growth of today's building technologies to achieve sustainability in buildings and reduce building energy consumption. These technologies are building envelopes, green roofs and walls, and photovoltaic systems.

The façade represents the front of a building. Moreover, the façade is an essential part of a building's energy efficiency and plays a crucial role in the internal function of the building. The study aims to evaluate the adaptive façade systems in Northern Cyprus to significantly clarify which types of façade systems are more suitable and whether adaptive systems work in the conditions of Northern Cyprus. The case study is colored building one of the Faculty of Architecture buildings in the Eastern Mediterranean University (EMU). And the analysis evaluates movable horizontal and vertical shading with integrated photovoltaic (PV) into façades northwest and southwest, the PV panels for generating energy, and shading for blocking and reducing energy usage in the building.

The simulation software was the Design-Builder and the calculation by Energy Plus for system load of the colored building. The result of the analysis provides an explanation and answer to the problems. The research method is a qualitative evaluation, simulation tools, and case study. Data collection was done through literature review and observation to obtain data about adaptive façade systems. And the analysis part of the case study colored building with the result evaluation of

Design-Builder, the total electricity end uses in CB without integrated PVs panels and shading is 656514.436 kwh. The energy that can be produced after integrated PV panels in horizontal shading in the southwest and northwest façades is 95062.464kwh. The energy that can be produced after integrated PV panels in vertical shading in the southwest and northwest façades is 96598.0144kwh.

Keywords: adaptive façade, sustainable building, energy efficiency, colored building, design builder, energy plus.

ÖZ

Sürdürülebilirlik talepleri etkili bir şekilde büyüyor ve ilerlemeyi artırıyor. Bu alandaki insanlar (inşaatçılar, mimarlar, mühendisler ve inşaat sektörü), binalarda sürdürülebilirliği sağlamak ve bina enerji tüketimini azaltmak için günümüz bina teknolojilerinin büyümesine ayak uydurmaya çalışıyor. Bu teknolojiler bina zarfları, yeşil çatılar ve duvarlar ve fotovoltaik sistemlerdir.

Cephe bir binanın önünü temsil eder. Ayrıca cephe, bir binanın enerji verimliliğinin önemli bir parçasıdır ve binanın iç işlevinde çok önemli bir rol oynar. Çalışma, Kuzey Kıbrıs'ta hangi tip cephe sistemlerinin daha uygun olduğunu ve uyarlamalı sistemlerin Kuzey Kıbrıs koşullarında çalışıp çalışmadığını önemli ölçüde netleştirmek için Kuzey Kıbrıs'taki uyarlanabilir cephe sistemlerini değerlendirmeyi amaçlamaktadır. Örnek olay, Doğu Akdeniz Üniversitesi'ndeki (DAÜ) Mimarlık Fakültesi binalarından birinin renkli binasıdır. Ve analiz, kuzeybatı ve güneybatı cephelere entegre fotovoltaik (PV) ile hareketli yatay ve dikey gölgelemeyi, enerji üretmek için PV panelleri ve binadaki enerji kullanımını engellemek ve azaltmak için gölgelemeyi değerlendirir.

Simülasyon yazılımı Design-Builder ve renkli binanın sistem yükü için Energy Plus tarafından yapılan hesaplamaydı. Analizin sonucu, sorunlara bir açıklama ve cevap sağlar. Araştırma yöntemi nitel bir değerlendirme, simülasyon araçları ve durum çalışmasıdır. Uyarlanabilir cephe sistemleri hakkında veri elde etmek için literatür taraması ve gözlem yoluyla veri toplama yapılmıştır. Tasarım-Builder'ın sonuç değerlendirmesiyle renkli bina örnek olay incelemesinin analiz kısmı, entegre PV panelleri ve gölgeleme olmadan CB'deki toplam elektrik son kullanımları 656514.436 kwh'dir. Güneybatı ve kuzeybatı cephelerde yatay gölgelemede entegre PV paneller sonrası üretilebilecek enerji 95062.464kwh'dir. Güneybatı ve kuzeybatı cephelerde dikey gölgelemede entegre PV paneller sonrası üretilebilecek enerji 96598.0144kwh'dir.

Anahtar Kelimeler: uyarlanabilir cephe, sürdürülebilir bina, enerji verimliliği, renkli bina, design builder, energy plus.

DEDICATION

Dedication to my mom. She made me believe in her famous saying, "Do more, know more," and that saying has become my way of life.

ACKNOWLEDGMENT

I am grateful to my supervisor Assoc.Prof.Dr.Ercan Hoskara, for his guidance and generosity in providing me with the information and feedback when I need it. I am grateful for his advice and precious time during the thesis steps.

I would like to express my heartfelt gratitude to committee members (Prof.Dr.Mujdem Vural, Assoc.Prof.Dr.Ercan Hoşkara, and Assist Prof.Dr.Sertac Ilter) for your encouraging words in my deepest appreciation.

I would like to appreciate the EMU family for everything that has been done and provided for me. Such as let me know and make some friendship, sisters, and relation with the staff there, I am much grateful for that.

My appreciation goes to the EMU family for everything that has been done and provided for me. I am so grateful to Emu for the greatest; an opportunity to know sisters and brothers and make some friends. And my appreciation and thanks go to Diler Haji for helping me with my research.

My sincere gratitude and thanks go to my friends for being there for me and pushing me. And my sincere thanks go to my friends whom I met during my master's study; Maymona, Maryam, Atheera, and El Mehdi. Some of my friends provided me with advice to keep going and motivated me. If I spent my whole life thank you, I would not be able to describe my sincere thanks in words. And, thanks to friends that did not believe in me and underestimated me, those things made to move forward.

Last but not least my, thanks, appreciation, and sincere love to my family: my mom for teaching me how to fight in life and believing in me when I did not believe in myself. My beloved sisters for pushing me and for being there for me. I know that you love me and trust on, so it's a mutual feeling; I can't find enough words to tell all of you that you are in my heart. From the bottom of my heart, thank you.

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LIST OF SYMBOLS AND ABBREVIATIONS

24/7	24 Hours a Day, 7 Days a Week
&	And
AF	Adaptive Façade
AVFs	Active Ventilation Façade
CB	Colored Building
CCFs	Closed Cavity Facades
CGF	Chromogenic Glazing Façade
DShF	Dynamic Shading Facade
EMU	Eastern Mediterranean University
HVAC	Heating, Ventilation, and Air Conditioning
KWH	Kilowatt Hour
NW	Northwest
PV	Photovoltaic
SAFs	Solar Active Façades
SW	Southwest

Chapter 1

INTRODUCTION

With rapid development in the construction section, there is a noticeable increase in carbon dioxide emissions, greenhouse gas emissions and energy usage. The building industry is attempting to address greenhouse gases from buildings and minimize energy consumption in buildings; by providing solutions that minimize carbon dioxide emissions and enhance the energy efficiency of buildings choosing environmentally friendly and sustainable construction. While offering new construction technologies and building materials that can help increase energy efficiency, this includes adaptive facades, PVs technology and energy-efficient building materials.

Adaptive façade technologies are the most sustainable technologies used today to combat overheating and make buildings more energy efficient. It could be accomplished through, by lowering heat transfer across the facade, and increasing free gains. The objective is to balance overall energy consumption with CO2 emissions and monitor access to energy sources and sinks in buildings (Goia F. 2013).

In addition, to the measures and laws that had been done in the developed countries in such construction, the technologies are examined to achieve the result so; that they can propose/present solutions to achieve energy efficiency and highlight the problem of Northern Cyprus.

This chapter focuses on earlier research on the adaptive facade system for energy efficiency and evaluation a case study by integrating photovoltaic (PV) into facade as shading to generating energy, by considering an advantage of searching for previous studies and reaching their research findings to broaden the boundaries of the information available in Northern Cyprus.

1.1 Literature Review

An adaptive façade is a new generation of integrated vertical systems whose primary objective is to minimize the energy consumption of buildings, increase the comfort of users and improve the sustainability of buildings (Favoino, F. et al. 2014) & (Xu X. & Van DS. 2008). Today's standards require the facade to function like an energy-efficient mechanical system that can respond to changing outdoor conditions to achieve efficiency and functionality, for instance, the façade must adapt or change (AccionaConstruccionSA, 2016). And the adaptive façade operates in a multi-functional manner, such as playing a major in blocking the solar radiation to access into the building, insulation, visual comfort, thermal comfort, ventilation, protection from the weather conditions, and structural integrity (Couvelas, A., et.al., 2018). The aim is to enhance the indoor conditions and achieve energy efficiency in the building. In the current era, an energy-efficient mechanical system is effectively used in the façade building that is potentially responsive to changing outdoor conditions to achieve efficiency and functionality (Bacha, Ch, & Bourbia, F. , 2016).

The façade is a fundamental parameter for the effectiveness of the energy performance of buildings, and its components must be designed to give the building the necessary flexibility in terms of energy flow and thermal comfort. The adaptive façade can improve the efficiency and economy of the building as it can change its behavior depending on the internal and external parameters through elements, systems, and materials. In addition, an adaptive façade can control thermal mass, radiant heat exchange, insulation, ventilation, energy harvesting, solar shading, daylighting, and humidity control (Aelenei, D. Aelenei, L. & Vieira, P. 2016).

From the view of building physics, the aims are to enhance the insulation of the building and to increase the energy efficiency of the building by reducing thermal transfer losses within the façade and increasing free gains.

(Loonen RCGM, 2010) argues that the word adaptive is part of the long list of similar words that describe building façades (accommodating, active, controllable, dynamic, adaptive, adjustable, innovative, advance, modifying, kinetic, interactive, transformable, movable, reflexive, reconfigurable, relative, polyvalent, switchable, transient, responsive, sensitive, variable, sensitive, intelligent, selective, smart, and elastic).

In Cyprus, there are various residential buildings that have been potentially constructed, and it has not been given attention towards the basic bioclimate that has potentially led to a dependence oversized that is potentially used for cooling heating spaces (Ogbeba & Hoskara, 2019). A building physics perspective, the goal of a building facade is to improve the insulation and increase building energy efficiency by minimizing and reducing heat transfer through the façade building and increasing free gains.

1.2 Problem Statement

According to the survey carried out by researcher to check if there exists any adaptive facade system in Northern Cyprus, the observation showed that there is no adaptive façade in Northern Cyprus. While the term sustainable construction in Northern Cyprus has been defined in terms of nearly zero-energy buildings which had integrated PV on the rooftop combined with solar thermal collectors to produce electricity for heating water in winter and for cooling in summer.

Adaptive façade technologies are sustainable technologies used to counteract overheating and increase the energy efficiency of buildings. However, it can be accomplished by reducing heat transfer through the building envelope and increasing free gains. The aim is to balance overall energy consumption and CO_2 emissions and control entrance to energy sources and buildings skin. One of the significant challenges is determining the functions of smart cities, significantly promoting economic growth, and effectively working to develop better lifestyles and quality of life (Karimizadeh, 2015). However, one question that can be asked about such a system is whether an adaptive facade system is suitable for adapting to the Northern Cyprus condition in terms of sustainable building.

1.3 Research Aims, Questions and Objectives

By looking at the mentioned problem, the research aims to significantly investigate adaptive façade systems, especially in the conditions of Northern Cyprus. And to clarify which types of adaptive façade systems will give better performance in the Northern Cyprus in the means of energy efficiency. The result of the analysis offers an explanation and answer to the problems and questions of the research.

Consequently, the main research question is structured as follows:

Adaptive façade in terms of sustainable buildings in Northern Cyprus is visible, is works, is sustainable and is a good choice. And the related to sub-questions:

- Which kind of adaptive façade systems can be good alternative for Northern Cyprus?
- Are the conditions in Northern Cyprus suitable for adaptive façades or not?

And the requests and current points above lead to objectives:

- To evaluate the adaptive façade system, whether it is a good or sustainable building in Northern Cyprus or not.
- To clarify the appropriate façade types for Northern Cyprus.
- Clarify whether adaptive façade works or is a good choice in the context of sustainable building in Northern Cyprus.
- To analyze and investigate whether the researcher can recommend the use of an adaptive façade system in Northern Cyprus.

1.4 Methodology

This study investigated the functionality of an adaptive façade system under the conditions in Northern Cyprus, and the research will be conducted using the qualitative research approach. Thus, the research will be focusing on non-numeric data. The secondary research design is used to gather the study's data, and the research is based on past research. It will potentially use the book authentic reports published by the other researchers. Qualitative research is potentially used in the study to determine the concepts, theories, perspectives of the researchers, and case studies approach which are five case studies the researcher chosen to analysis them.

Cases study is colored buildings in the Eastern Mediterranean University (EMU) faculty of architecture in Northern Cyprus Famagusta. The evaluation of colored buildings case is based on the survey and analysis of the condition of building to adaptive façade work or not, that by adapt shading into the façade and then integrated

PV to generate energy electricity. And the simulation software used was Design-Builder calculate annual energy generation from integration PV into façade and calculate the energy consumption of the building before and after integrate PV. Data collection is done through literature review, personal observation, and case studies to obtain information about adaptive façade systems, façade applications, and façade typologies, are effectively used in the study to determine the conditions in Northern Cyprus and critical analysis.

1.5 Limitation of the Study

The study is limited to the visibility and functionality of using an adaptive façade in Northern Cyprus under sustainable conditions. Thus, the study is significantly limited to Northern Cyprus and does not focus on other countries. The data used in the study is potentially based on observation rather than using interviews and questionnaires. Therefore, this study is limited to evaluating the adaptive façade based on the results of the analysis and discussion and to evaluating the colored buildings' adaptive façade to generate energy from the PV shading.

1.6 Thesis Structure

This thesis provides the reader with an understanding of the adaptive façade in the context of sustainable buildings in Northern Cyprus conditions. In the five chapters, the structure of the thesis is explained as follows:

Chapter one provides an introduction and background, the problem statement, questions, the objectives of the thesis, the methodology, the limitation of the study and finally, the structure of the thesis.

Chapter two provides a theoretical background: which is divided into two parts: part one adaptive façade: the definition of building façade, façade elements, adaptive façade definition, classification of adaptive and façade typologies. And part two cover five case studies which are S2OSB Head quarts And Conference Hall, Kefir Technic showroom, ALBahr Towers, Cologne Oval Office Building, and Freiburg Town Hall.

Chapter three cover sustainability focuses by focusing on sustainable development, then moving on to sustainable construction and finally, to sustainable building adaptive façade with environmental and economic dimension.

Chapter four presents the details of applying the significantly used methodology to conduct the study.

Chapter five deals with the conclusion and the recommendations that a researcher would make for the usability of the adaptive façade in Northern Cyprus.

Chapter 2

THEORETICAL BACKGROUND

This chapter provides a theoretical framework and is divided into two parts: part one covers the definition of the building façade, façade elements, adaptive façade definition, classification of adaptive façade and finally typologies of adaptive facade. And part two covers case studies building of adaptive façade from different countries which are Germany, Abu Dhabi, Turkey, and Austria.

2. 1 Definition of Building Façade

The building façade provides the separation between the inside and the outside environments but is also required to provide acceptable light levels and a visual connection with the outside in the form of views out of the building. The façade may also be required to provide the building user with openable windows for ventilation (SteelConstruction.info, 2022). Building facade means the front or principal face of a building. The total area of the building façade, including windows, doors, trim, etc., should be used when calculating the percentage requirements of this Code related to building façade (Insider, 2022).

2. 2 Façade Elements

Each façade element is connected to the building structure with angled cleats installed near the ceiling. The element is suspended from the top and attached to the element below by a bolt that stabilizes it against lateral forces at the base. In this manner, successive elements can be stacked or connected, either in a row or from bottom to top

(Knaack, U. et.al., 2007, p 60), and there two types of façade system elements structural facade and non-structural façade.

2.2.1 Structural Façades

Façade systems comprise the structural elements that provide lateral and vertical resistance to wind and other actions and the building envelope elements that provide the weather resistance and thermal, acoustic, and fire-resisting properties. The types of façade systems that are used depend on the type and scale of the building and on local planning requirements that may affect the building's appearance in relation to its neighbors. For example, brickwork is often specified as the external façade material, but the modern way of constructing the inner leaf consists of light steel wall elements (called infill walling) that have effectively replaced more traditional blockwork (SteelConstruction.info, 2022). The functions are spread among several distinct components. This configuration makes it easier to connect individual façade components and offers alternatives for compensating for moving elements. The major structure takes on the full building's load-bearing role and transmits the loads from the façade to the foundation (Shahabi, 2018).

2.2.2 Non-Structural Façades

Non-structural counts such as infill walls, Façade, stairs and so on considered as non-load bearing components. These components are asumed to be detached from the primary structure in the design of high-rise building. Moreover, non-structural components make a considerable contribution to the overall structural performance (Li, B., Hutchinson, G., & Duffield, C, 2010).

2.2.2.1 Post & Rail Façade (Stick System)

Stick wall systems are counted as the earliest design for curtain wall systems. They were extensively used in metal curtain wall systems and nowadays they are still used in greatly superior versions (Pakishan, 2011), (Figure 1) shown diagram of stick system curtain wall.

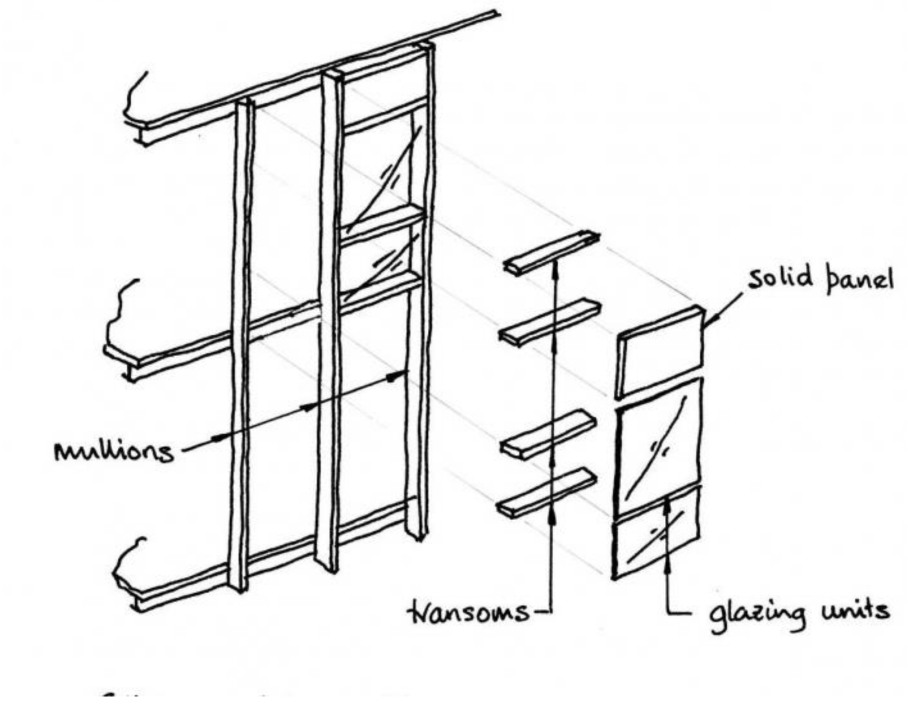

Figure 1: Shows Diagram of Stick System.

2.2.2.1.1 Curtain Wall

In the potential structural context, the significant facade that hangs from the front of the roof can be potentially considered the essential development of the curtain walls. The constructions are specified independently of the buildings from the main load-bearing structure. According to systems, the facade hanging from the front of the roof can be considered precursors to the development of curtain walls. The facade can be divided according to which essential cladding or extensive glazing is used to help in meeting the various aesthetic or potential functional demands (Knaack, U. et.al., 2007), (Figure 2) shows section of curtain wall façade north-City front-plaza Building.

Figure 2: Shows Section of North-City Front-Plaza Building, URL11.

2.2.2.1.2 Double Skin Facade

One of the most facade systems developed, which noticed these days. A system has a multifunctional function rather than installing a ventilation system into the building; the gap between two layers is used for ventilation and thermal insulation of the façade (Figure 3) shows section of double skin facade. Can, be gained double facade by adding a different layer of glazing outside the facade to give the building ventilation or soundproofing (Knaack, U. et.al., 2007). There are four construction typologies of double-skin facades that are:

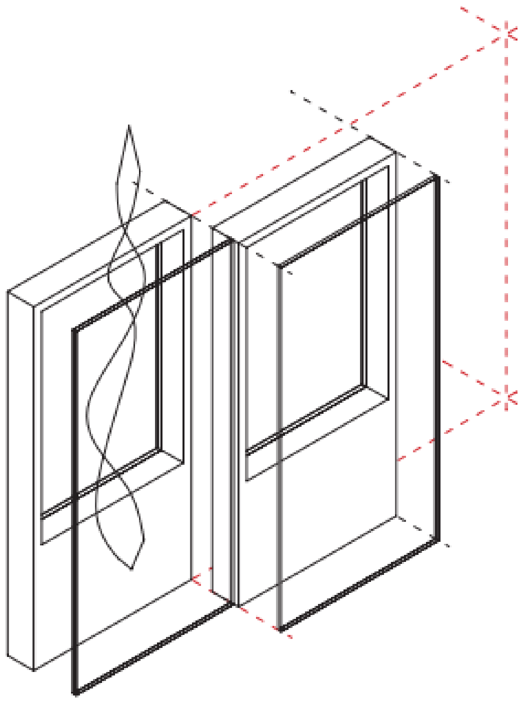

Figure 3: Shows Diagram of Double Skin Façade (Knaack, U. et.al.,2007).

a. Box window Facade

The box-window façade is based on the principle of the box window but consists of story-high façade elements. The interior windows can be opened for ventilation into the gap between the two façade layers as shown in (Figure 4), while the exterior façade comprises openings for supply and exhaust air (Knaack, U. et.al.,2007).

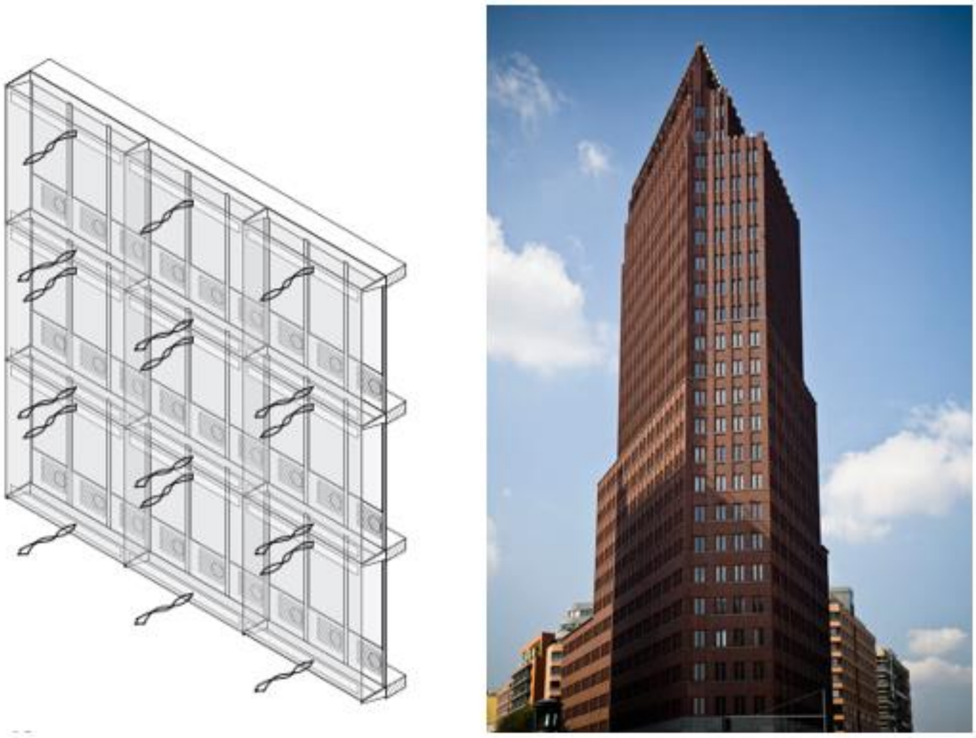

Figure 4: Shows on Left Section of Box Window, and on the Right Daimler-Chrysler Building, Potsdamer Platz, Berlin, Hans Kollhoff, 1999, (Knaack, U. et.al.,2007).

b. Shaft Box Facade

The shaft elements extend across several stories, and the vertical shafts are connected to the box windows via overflow openings story by story. Due to a stack effect, the warm air flows from the façade gap through openings at the head of the element through the shaft to the outside. The exhaust air can be extracted from the façade gap mechanically. The most effective double-skin façade, releasing their used air featured by box windows into a shaft extending over many floors (Poirazis, 2004).

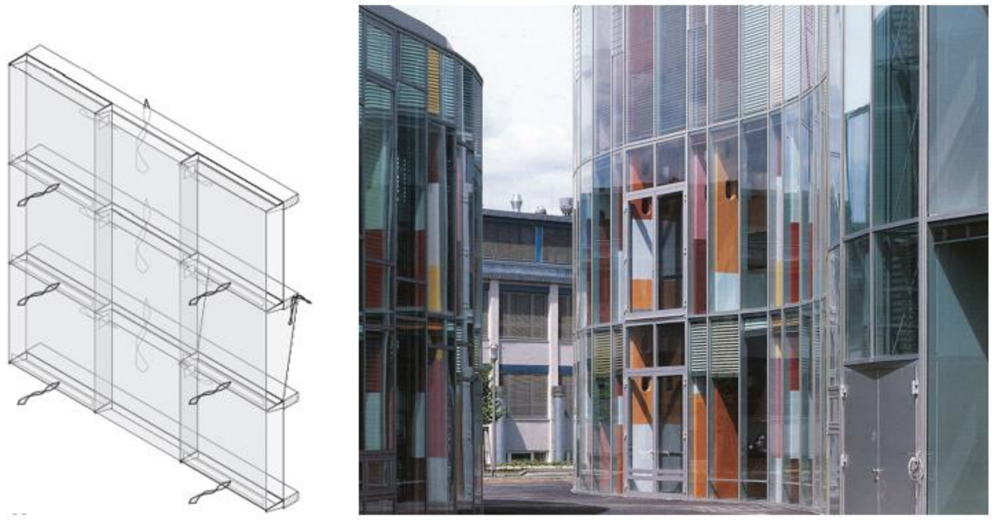

Figure 5 : Shows on Left Section of Shaft Box, and on The Right Photonics Centre, Berlin-Adlershof, Sauerbruch Hutton Architects, 1998 and, (Knaack, U. et.al.,2007).

c. Corridor

Corridor façades manage the airflow story by story, whereas in some cases, vertical dividers are added for fire or sound protection that might happen through the gap between the interior and the exterior facade layer, (Figure 6) shown corridor façade concept. While the function of the corridor facade is to deal with the intervention problem between the freshening systems at different levels with crossed air inlets and outlets, use the vertical baffle in the spaces between two skins, (Knaack, U. et.al.,2007).

Figure 6: On Left Section of Shaft Box Facade, And on The Right ARAG Tower, Düsseldorf, RKW Architektur + Städtebau with Foster and Partners, 2000, (Knaack, U. et.al.,2007).

d. Multi-story (Second-skin Façade)

Multi-story DSF are decoded with an expansive volume of air space between glazed layers without any partitions neither vertical nor horizontal direction, which prevents the airflow through the cavity as shown in (Figure7). Mainly to support cleaning and maintenance reasons, the introduced cavity between glazed layers is sufficiently wide-ranging to allow approach for the occupants from each floor level, which can be also promenaded, (Knaack, U. et.al.,2007).

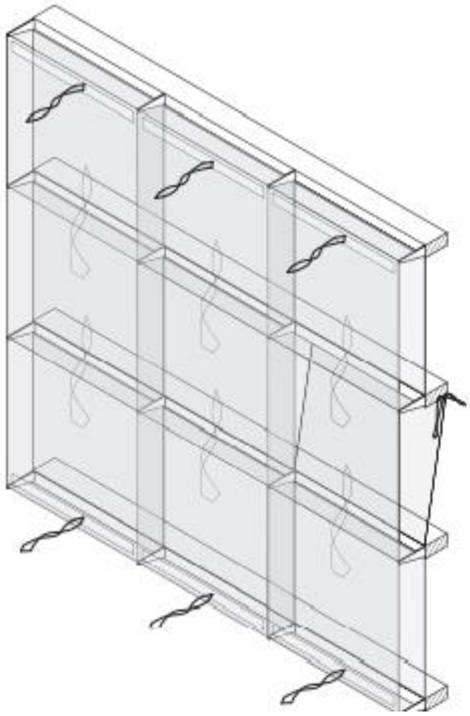

Figure 7: Shows Second-Skin Façade

2.2.2.2 Prefabricated Façade (Unitized Façade)

Significant unit systems rely on which type of construction could be prefabricated several wall elements and gathered onsite. The curtain walls potentially utilize used partitioned into an appropriate pole. Or manufacture the whole wall of a system that offsite and connect it as a complete, can be utilized on high rise buildings. The advantages of this system do not need plenty of labor numbers onsite and are uncomplicated when it comes to the assembly (Knaack, U. et.al., 2007).

2. 3 Definition of Adaptive Façade

In general, adaptation means that the buildings and the façade adapt to the current weather conditions. In addition, the façade is a control layer that can act as a link between the interior and exterior, allowing environmental conditions to be exchanged through the façade when necessary.

"According to the COST Action's an adaptive façade, definition, is a construction cover made up of multipurpose and highly adaptive systems which can alter their functions, characteristics, or attitudes over time in response to temporary performance requirements and limit conditions, with the aim of enhancing overall performance of the building" (Loonen et al., 2015).

2. 4 Classification of Adaptive Façade

According to members of the working group (WG1) and COST action of adaptive technologies and products, presented analytical approach defining structures and substructures facade. And this approach also classified adaptive facade based on database case studies into three main groups: materials, components, and facade system (Aelenei, L., et al., 2018). (Figure 8) shows Case study classification diagrams of adaptive façade (AF).

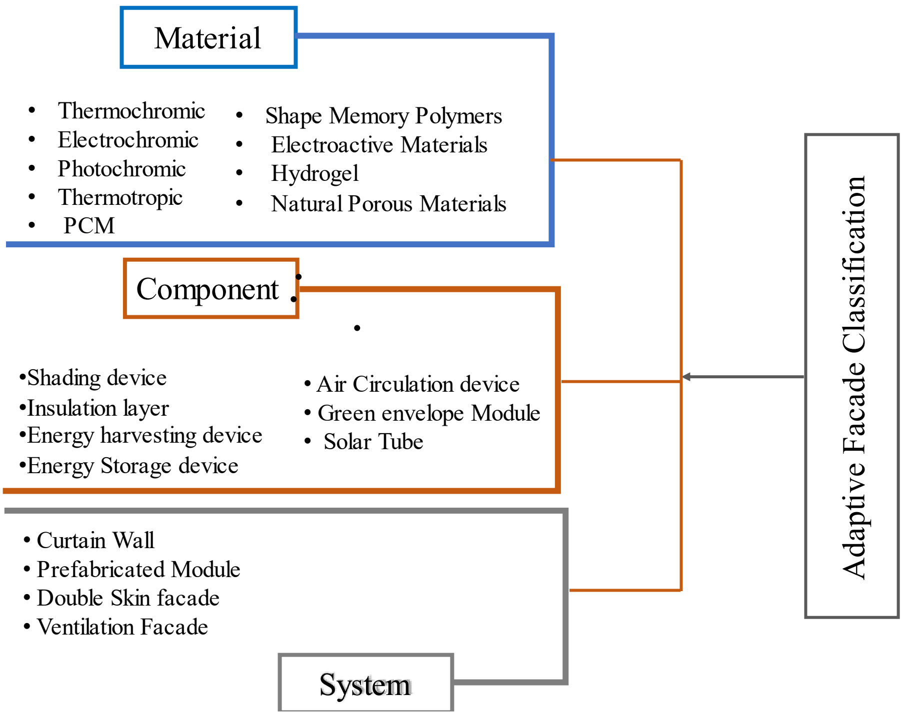

Figure 8: Case Study Classification Diagrams of AF (Aelenei, L et. al, 2018, p.13).

2.4.1 Materials

Materials from the perspective of the built environment; are playing a crucial role in operational power consumption. And structural improvement is explained by limited conditions. The collection of functions of these materials determines the practicable performance criteria for surface of an element as in integrated façade systems.

According to (Addington & Schodek, 2005) characterized intelligent materials as systems that have built-in technology functions that include specific responses to the environment through changes in internal physical properties or outside energy changes (Velikov & Thun, 2013), they defined intelligent materials' characteristics as instantaneous transient inertial selective and direct.

2.4.2 Components

As a set of several parts, it formed a finished or functional structure element as an element of a façade, such as a glass panel that is insulated, a solar shading device, and a window frame with glazing as the components of the system. In addition, adaptive façade components act on an extrinsic stimulus with low environmental impact and at an affordable price. The durability and life cycle of the element are fundamental to the future of the application. The function of the component façade does not shorten inefficiency in energy exhaustion (Aelenei, L., et al. 2018, p. 55).

2.4.3 Systems

It consists of several translucent or obscure structural or technical elements and functions as insulation from environmental factors like rain and wind tight. For examples of façade systems are curtain walls, prefabricated modules, double skin façade and ventilated façade (Romano, R, et.al., 2018).

Adaptive facade systems can be minimized to zero energy consummating of buildings that they integrated, and the aim was to enhance the sustainability and comfort for cities. In addition, the envelope system converted from passive technical solution to active systems ability to generating renewable power and cable in a fluid and adaptive façade system spatial formations and performance of its outer layer to enhance internal comfort condition (Aelenei, L., et al., 2018, p. 101).

2.4.4 Adaptive Facade Technologies and Categories

The research significantly determines that technologies of adaptive façade are categorized into the family. The classification is based on the expert's knowledge of each technology's market needs (volume of scales), and the four categorize families: 1) dynamic shadings, 2) chromogenic facades, 3) active solar façade, and 4) active ventilation façade. It potentially represents promising chances in the future and the market. And (Figure 9) shows the adaptive facade technologies and categories (Attia Sh., Lioure R. & Declaude Q. 2020).

Dynamic Shading Facade DShF

The purpose of DShFs is to block sunlight, thermal insulation, summer comfort, cooling and heat effect and the control manual and automated. Thus, there are four different types of DSF categorized: shutter, roller, ventilation, and closed cavity façade natural ventilated.

Chromogenic Glazing Façade CGFs

The core component of CGFs is solar, significantly gathering daylight and controlling it, minimizing cooling demand, effectively providing summer comfort, and reducing glare. Depending on the types of GCF's, the potential control can be automated, environmentally activated (passive), and this type is categorized into three classifications: electrochromic glazing, liquid crystal glazing, and thermochromic glazing.

Solar Active Façades SAFs

SAF is significantly an effective solar gain and daylight mechanism that aim to decrease cooling demand effectively provide summer and enhance winter comfort, glare reduction, heat, and solar energy storage. It significantly controls active, environmentally active control, environment active, and automated. And this type is categorized into three double-skin façade, green façade and roof, and phase change materials.

Active Ventilation Façade AVFs

The purpose of AFVs is gain solar energy and control daylight, minimizing cooling demand, providing extensive summer and winter comfort, reduce glare, heat, and solar energy storage. It can potentially adapt to the changing boundary conditions in short term weather fluctuation. And the control on demand, this type categorized into two actively ventilated CCFs and automated operable windows.

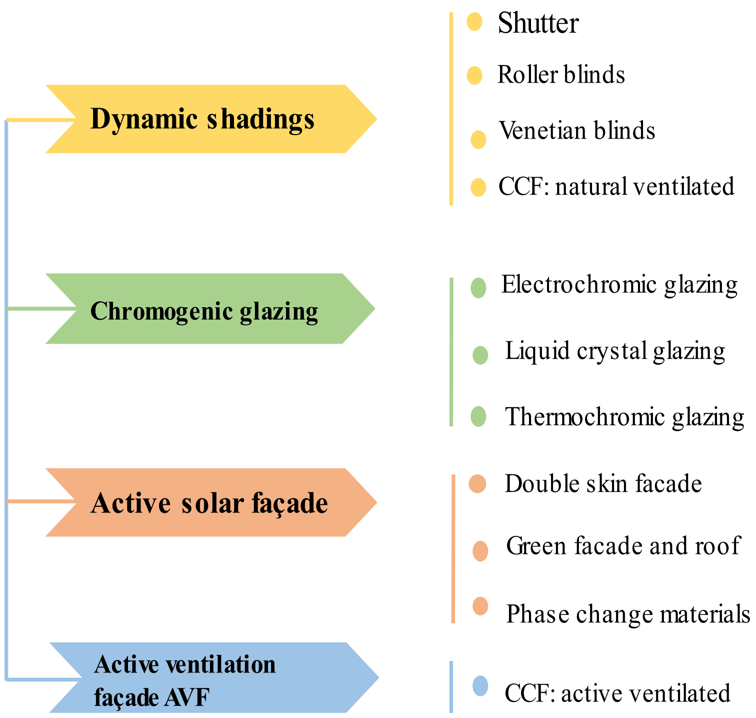

Figure 9: Shown Diagram of Adaptive Facade Technologies and Categories (Attia Sh., Lioure R. & Declaude Q., 2020).

2.5 Typologies, Control and Movement of Adaptive Façade

The concern in developing and designing adaptive façade that potentially includes the diverse materials façade systems and material that has grown compared with the historical decade. The originations in the finishing field and the technological developments for effective solar control effectively design adaptive façades with an approachable, aesthetic, and intellectual feature. The technologies enable buildings to perform better and meet users' comfort and solar control demands by acting on various external factors. Therefore, adaptive façade finds in the shape of several technologies, materials, components, and systems, that appeared in near relation to façade requirements, and it is effectively explained in (Figure10), (Aelenei D, Aelenei L, Vieira CP., 2016).

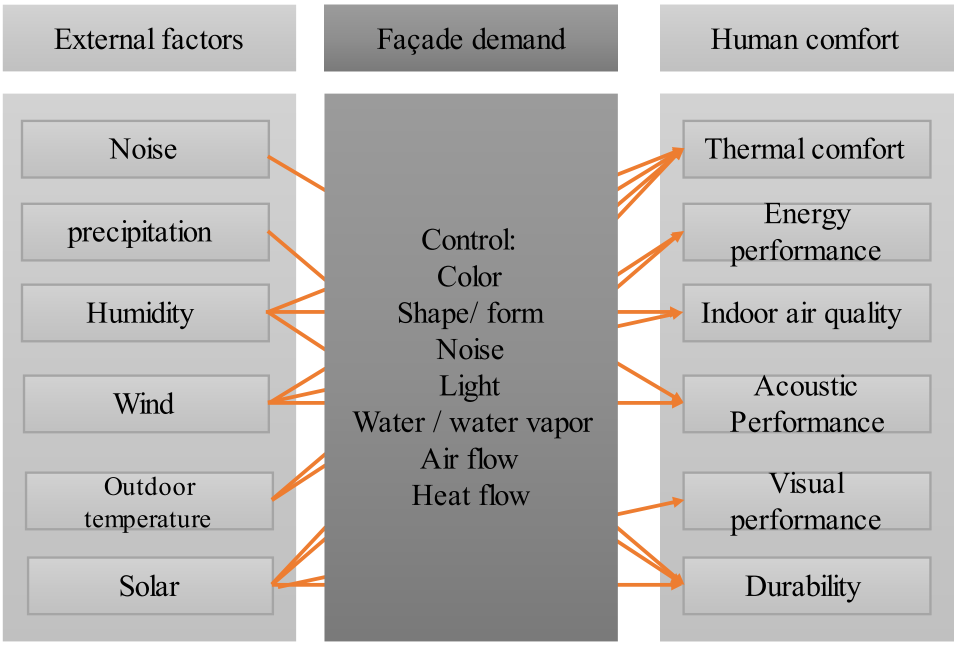

Figure 10: Schematic Role of Adaptive Façade (Aelenei D, Aelenei L, Vieira CP., 2016).

Despite aspects of adaptive facades technological, the adaptability is global as the most prominent source of inspiration between current adaptive technologies. The possibility is vastly used within a biomimicry approach to imitation nature such as plants and animals, transforming a building envelope into a living organism.

2.5.1 Typologies of Adaptive Façade

Adaptive facade typologies are categorized based on the nature of the system in the context of adaptability and technological controlling measures that determined their basic requirements as summarized in earlier studies. ((Loonen. R.C.G.M, Trčka. M, Cóstola. D, Hensen. J.L.M. 2013) & (Matin. H .N., Eydgahi, A. & Shinming. Sh. 2017)). The previous reviews ((Al-Obaidi. M. K, et al. 2017), (Fiorito. F. et al. 2016) & (Thun. G. & Velikov. K. 2012)) categorized adjustable facades into many types: active, advanced, biomimetic/bio-inspired, kinetic, intelligent façade, interactive/media, movable, responsive, smart, switchable, and transferable.

2.5.1.1 Active Façade ACF

The active facade can be definite technological systems " elements through which buildings self-adjust” to changes due to their indoor and outdoor environment (Wigginton, Harris J. 2002 & Lee E, et al., 2002). However, it depends on it can be technological adaptability using the automatic, or it can be manual modern electronics.

2.5.1.2 Biomimetic Façade BF

Biomimetic facade the concept of it based on the imitation and inspiration of skin of plants and animals. And have multifunctional and sustainable enclosure systems, the function of the biomimetic facade can be in two different types it can be direct or indirect. The direct method duplicates the efficient principle observed in technology used for the building facade that was potentially transformed in certain roles. In contrast, the indirect method principle abstraction steps are essential for the intermediate in translating it from a genetic principle to a building facade technology (Sheikh,W. & Asghar, Q., 2019).

2.5.1.3 Kinetic Façade KF

Zuk and Clark explained kinetic architecture is a type of architecture that can move be inflatable or able to move (De Marco, Werner 2013), whereas (Loonen, R.C.G.M. 2010) defined a kinetic facade as a technical system that has a specific type of movement, with the ability to guarantee in variable positions or be mobile geometry characteristics in some part or all (Fox & Yeh, 1999). In other words, it demands flexibility in terms of location, mobility, or geometry of its elements. Moreover, the word kinetic refers to an organism that responds to a specific category of inducement in biology (Wang et al., 2012) and can temper energy in its primary forms; an evident, light, and thermal energy. The ability to respond to the energy flows with details, whether natural or manufactured fundamentally, affecting the building performance and users' comfort (Fortmeyer & Linn, 2014). These kinds of; need to be adapted proficiently for borderline situations, such as weather conditions, numerous locations, changing functional requirements or emergencies to ensure kinetic an operating force that generates movement is required.

2.5.1.4 Intelligent Façade INF

The term intelligent means a higher order of organization and performance than "smart". Brain Atkin describes "intelligent" buildings as those that "know" the environmental condition (internal and external) that "decide" how to create a comfortable and convenient environment for users and respond immediately to users demands (Atkin, 1988). The "intelligent" building facade aims to improve the building systems for the weather, power stability and human comfort, usually according to predictive models.

2.5.1.5 Interactive Façade IAF

The word interactive barely used frequently in building envelopes than refer to computer artwork installing, whereas interactive envelope difficulties input of human to start answer and may also need equipping with devices and a programmed building management system and automated to improve energy saving during confirming the well-being of occupants (Velikov & Thun 2013).

2.5.1.6 Movable Façade MF

A movable facade refers to a technological system that can be modified rapidly to adapt to local conditions while also defined by its opening element. In addition, the workability of the system when the single parts of the flexible enclosure along with PV elements to equipped that potentially monitor and identify the place of the sun. Certain enveloping types of systems can generate clean energy, it potentially reduces energy usage in new or old buildings (Schumacher, Schaefer & Voght 2010).

2.5.1.7 Responsive façade REF

According to (Ferguson et al., 2007), functional responsiveness in contemporary architecture refers to a system that can potentially adopt changes that support intended functionalities. It includes various f conditions using the design changes, especially in the case of physical properties. An approachable facade plays an energetic character and fluctuations to a greater or lesser degree based on the meaning of complexity or simple calculation (Negroponte, 1975). Yet (Meagher, 2015) described a responsive facade as a comfort building element that adjusts to the needs of humans to change in the environment.

2.5.1.8 Smart Façade SF

(Klooster, T. 2009) and (Addington& Schodek) identify smart materials; as systems possessing (technical functions that are embedded) system processing effectively use the technological functions that are significantly involved within the environmental potential environmental response, it is, however, operating along with the internal physical property or external exchange various examples help in understanding the smart concept materials that are used in building skin to enhancing the performance of an organization the low density synthesizes material that is transfer rated it is effectively used in window glasses material such as face-changing also use along with the microencapsulated wax etc. (Velikov & Thün, 2013).

2.5.1.9 Switchable Façade SWF

Switchable facade an adaptive facade is a transparent facade with smart glasses generally, smart materials that can control how much light and energy flows through it (Beevor, 2010).

2.5.2 Adaptive Control

Control facade is a curial factor for the adaptive facade that should consider in the design stage, users' operation, and automatically operated control mechanisms that can integrate into façade conception towards achieving lower energy demands. In comparison, to ensure the environmental quality of the indoor spaces, (Figure11) shows the adaptive control strategies for façade design. So, the actuators are connected between environmental conditions and adaptive façade system, providing the machine with information about changes in specific outdoor conditions. The sensors, consequently, are related to the stimuli detected by the sensors. There are two types of control: local and central control (Velasco et al., 2015).

Reactive methods based on deterministic procedures; determine if conditional actuator-based behavior should result in decisions of different levels. Local control strategies are implemented; at the components scale, which suggests that the sensor is autonomous; and the control may be integrated in anisotropic materials or connected to exclusive actuator-based systems. However, the central control strategies applied into spaces scales; suggest multiple elements, which are directed; by a single unit via a direct method, and do not request input from sensors as all actions are pre-programmed. The system-based approach is based; on random procedures, while the goal is to solve complex problems via base data processing inside the console.

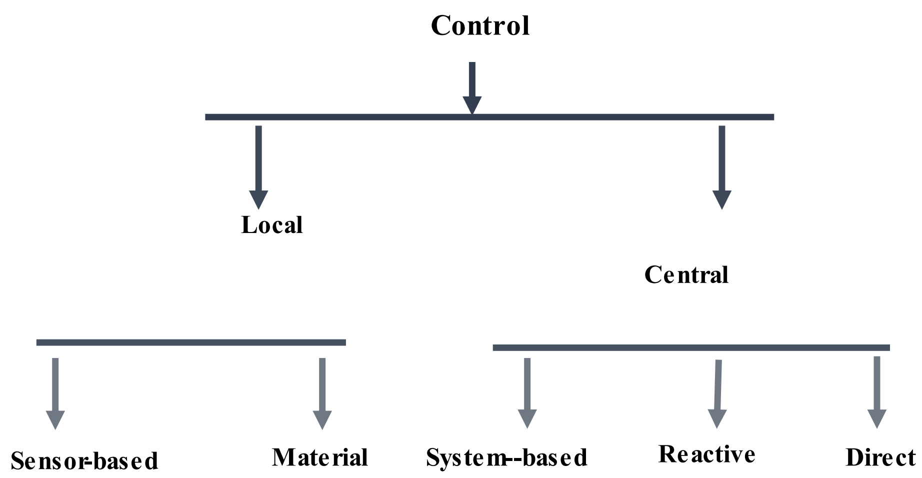

Figure 11: Shows Diagram of Adaptive Façade Control (Velasco et al., 2015).

2.5.3 Adaptive Façades Movement

According to their movement typologies, the categorized adaptive facades are into two main groups: the first type simple motion and the second type complex (Table 2.1) explain energy involvement adaptivity typologies, controls, actuation, and complexity level. The two groups utilize passive and active strategies in terms of energy sharing. The passive method does not require elementary energy to create adoption like manual control responsiveness surface, on the other hand, the active technique, necessitates energy input and relies on mechanical-based sensors (Martinho, 2019).

The simple motion corresponds to a conventional adaptive façade with simple geometries like roller shades and venetian blinds. The adaptability is limited to translation/ rotational movements, and the operation is through passive (e.g., Cord, rods) and active (electro-mechanical) sensors. In terms of control can be automatically (without user intervention) or users' control.

Non-conventional adaptive facades are based on complex movement types and are divided into three types: 1) basic movement, 2) folding structure and, 3) biomimetic skins (Kim et al., 2009).

Basic Movement

It refers to a multi-unit device or grid-based duplication of grid bodies. That contains several shading units in the façade and can adapt through a single or multiple basic movement types. And there have three types:1) Translational motion, 2) Rotational motion and 3) Combining translational and rotational movement **(**Moloney, 2011**)**. (Figure 12) illustrate the basic movement of façade and it transfer.

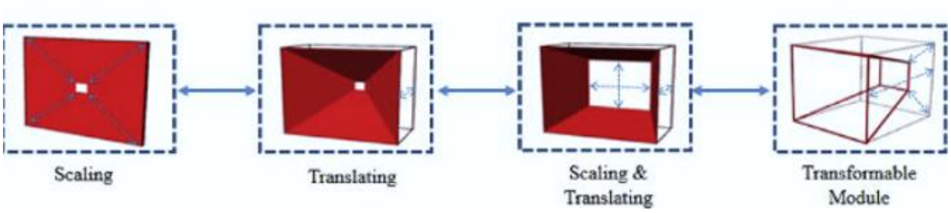

Figure 12: Basic Movement (Hosseini S, Mohammadi. M & Guerra-Santin. O, 2019)

Folding Structure

A foldable structure applies to 3D change ever façade specific to balance solar radiation, daylight and view outdoor to utilize folding structural as a shading device. There are two techniques found 1) rigid origamis and 2) curved-line folding (Kim et al., 2009).

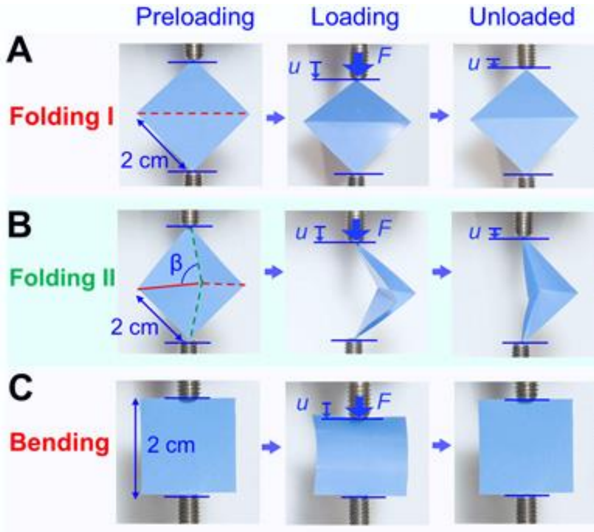

Figure 13: Shows Folding Structure Movement (Zhai, Z. Wangken, Y. Lin, K. Wu, L. & Jiang, H.2020).

Biomimetic Skins

Is new technology innovation coming as a solution to fulfil the gap which, is materials-based sensors to drive unconventional adaptive façade adjustment in the future. And this innovation of biologically inspired material processes characterized their natural organisms respond to inside and outside stimulants that may not need power and maybe needless energy, (Figure14) shown the concept of biomimetic transforming. According to (Al-Obaidi. et al., 2017), the sensors provide mixed methods of passive and active strategies derived from the biomimetic principle and can categorize into two material groups: 1) active as smart materials and 2) passive as adaptive materials.

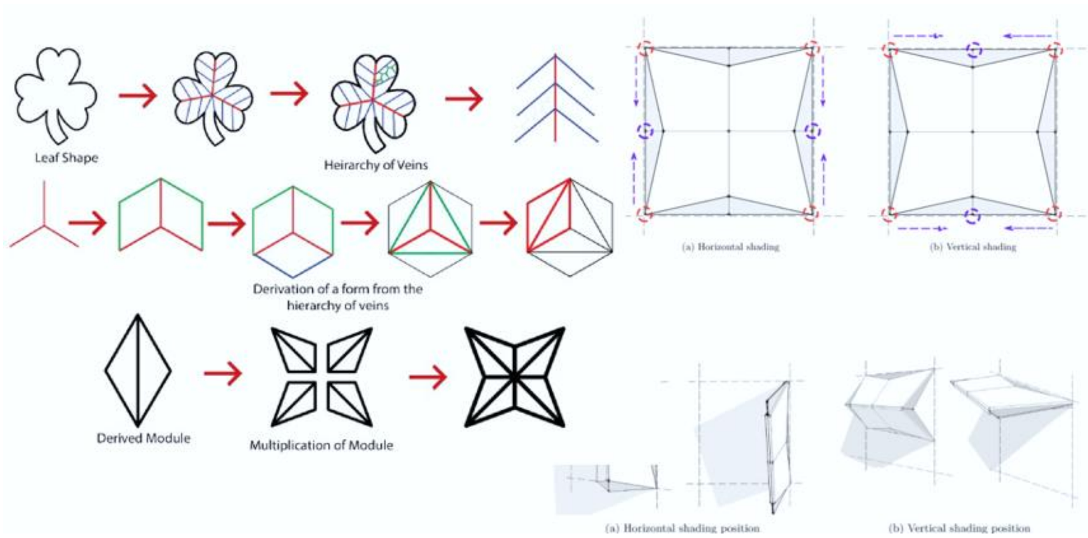

Figure 14: Shows the Concept of Biomimetic and How It Transforms (Tariq. W & Asghar. Q, 2019).

Table 1: Illustrate decomposed conventional and non-conventional types of AFs.

		Energy Involvement	Actuation Type	Control	Complexity level
Conventional	-Light shelf	Active	Mechanical -based	Automatic (open-loop, close-loop)/ Occupant	Simple (motion layout)
	-Venetian Blinds				
	-Roller Shade	Passive		Occupant	
Non-Conventional	-Basic movement	Active	Mechanical -based	Automatic (open loop)/ and Occupant	Complex (motion layout)
	-Folding structure	Active	Mechanical -based		
	-Biomimetic Skins	Active & Passive	Material-Based	Automatic (open loop)	

2.3 Case Studies

In this section the researcher study five case studies in four different countries, the researcher study them according to their typologies of adaptive façade and climate.

Case Study 1 S2OSB Headquarters & Conference Hall/ Hendek Turkey

S2OSB is a pioneering management building, headquarters, and conference hall. The façade, made of thoughtfully crafted metal, wraps around the building. And the material used for this façade is aluminum specs of the metal are 3mm aluminum sheet, alloy 5754 & tempered H22. Façade panels making process consists of (1500x3000) mm-sized sheets being satiated folded, and anodized (Yavuz, 2021).

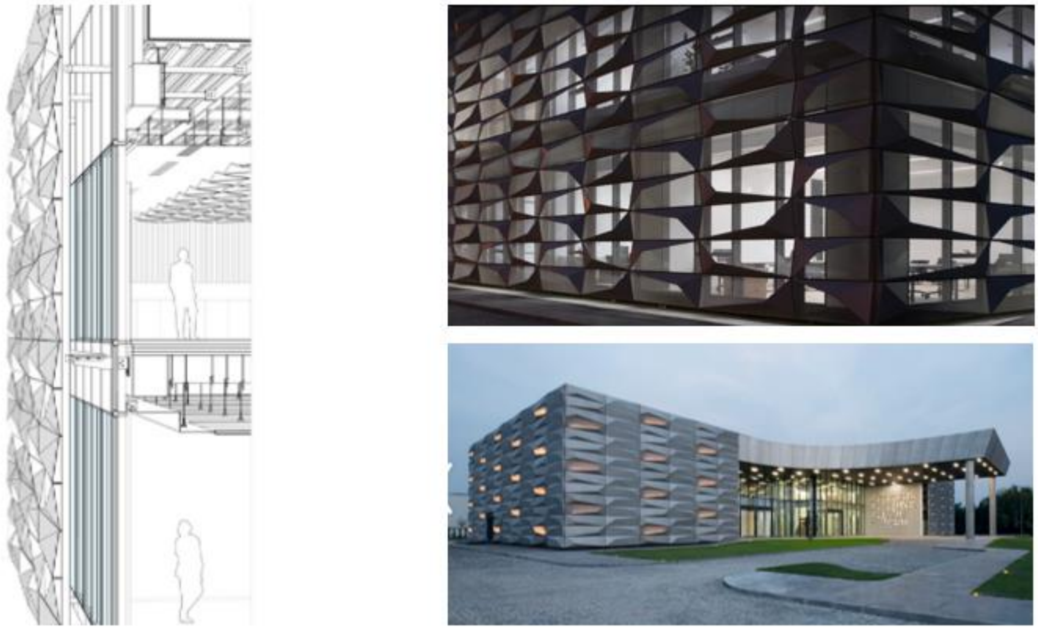

Figure 15: The left Show Section and In Top Right When It Open and The Bottom Right Shows When It Closed, S2OSB Headquarters & Conference Hall / BINAA Hendek, Turkey, URL10.

Case Study 2 Kefir Technic Showroom/ Austria

Present the Kiefer Technic Showroom, an office building and exhibition space with a dynamic facade that changes, to outdoor conditions, optimizing internal climate while allowing users to personalize their own spaces with user controls.

The facade consists of aluminum posts and transoms with protruding bridges for maintenance, with an EIFS-facade in white plaster. The sunscreen operates on electronic shutters of perforated aluminum panels (Vinnitskaya, 2021).

Figure 16: Shown the Responsive Façade the on Left When It Fully Open, on the Middles Semi Closed and, on the Right, Fully Closed. Kefir Technic Showroom, Badgley Chenberg, Austria, URL9.

Case study 3 Al Bahr Tower/ Abu Dhabi

Bahr towers consist of two 25 stories one tower houses the new headquarters of the Abu Dhabi Investment Council (ADIC), an investment arm of the Government of Abu Dhabi. The other serves as the head office of Al Hilal Bank, a progressive and innovative Islamic Bank.

The design concept is based on the combination between Bio-inspiration, Islamic Architecture "Mashrabiya" and performance-based technology. Mashrabiya is a wooden lattice screen found in Islamic architecture and used as a shading device to achieve privacy is the main idea and works to control ventilation, solar gain, and glare reduction.

The envelope of the towers covered with weather-tight glass curtain wall is composed of unitized panels separated from the kinetic shading system through a substructure by movement joints. The dynamic shading system screen consists of triangulating units like origami umbrellas, and the units work as a single shade device unfold to various angles in response to the sun's movement to block the solar radiation. Every Mashrabiya visualizes; a unitized system cantilevering (2.8 m) from the basic structure. Control of shading screen by computer-controlled to respond to optimal solar and light conditions. Mashrabiya shading device is collected into sections and worked by sun-tracking software to control the open and close gradation according to the sun angles (Attia, S., 2017).

Figure 17: AlBarh Towers Abu Dhabi, Aedas Architects, 2012, URL12

Case Study 4 Cologne Oval Office Building/Germany

Cologne Oval Office Building took as an example of a switchable in (Figure 2. 18) shows the façade. A façade concept is full-high windows and fixed panels of insulated double-glazed units. And the control can be manual by users which, is open windows and the vertical finlike glass louvres provide shade to the building and can use computer operated which is control in each office, the vertical axis glazed sun louvers serve the purpose of light regulation and, simultaneously, perform as outstanding architectural façade element, (Loonen,R.C.G.M. et.al, 2015).

Figure 18: The Oval Offices in Cologne (arch. Sauerbruch and Hutton, 2010) & URL3.

Case Study 5 Freiburg Town Hall/Germany

The building consists of two different blocks, and it is determined that oval office buildings tend to have an office building and an effectively designed rounded children's day-care center, as shown in (Figure 19). The upper floors are single, double offices, and it has an extensive team and the efficiency to work to open plan desk and arrangements. It potentially gives importance to the individual departments of the City Administration. And the three oval office building consists of a six-story building service center is the situation on the first floor, and two important things are located. Both are diverse conference rooms for conducting serious meetings and a staff restaurant for relaxing.

Moreover, the building-integrated PV module into the roof and façade building.; the vertical PV panels are integrated as solar-shading devices into the façade. Optimization of daylight intake is utilized along with Story-high glazed facade elements. The crystalline glass module integrated into; the facade with swiveled 36 degrees far from facade planes, as shown in (Figure 2. 19). The slender aluminum brackets that project at the level of the floor slabs carries these facade elements.

Suction and injection wells and thermal solar panels are effectively used for developing the energy obligatory for the building using a potential mixture with heat pumps. In addition, electric power that generated by photovoltaic panels on the roof and in the facade. Thermal mass activation is used for heating that individual controlled in each office (Detail, 2022).

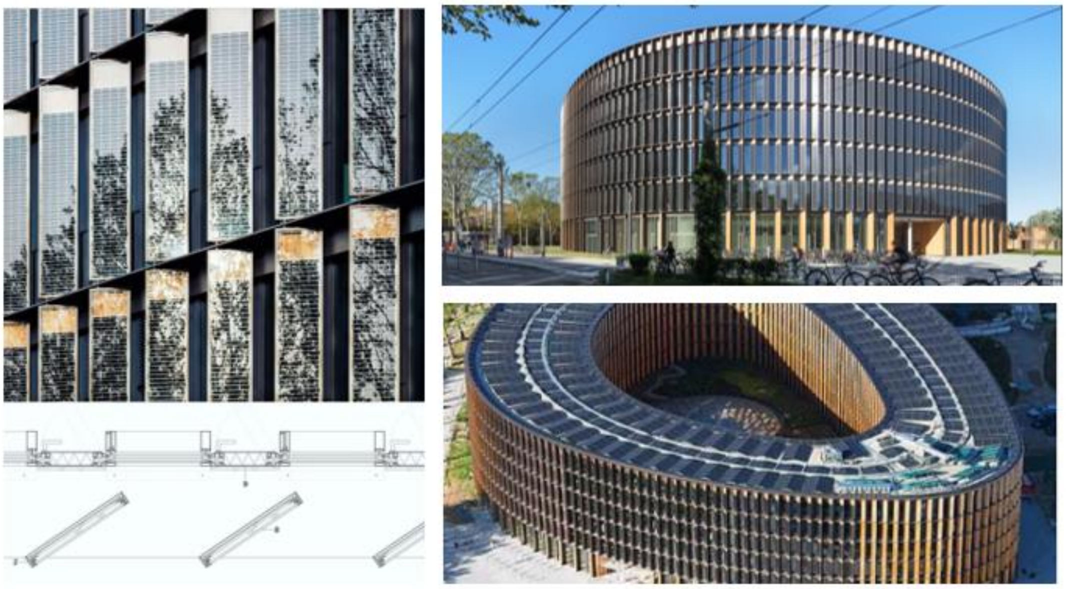

Figure 19: The Hall Town Façade, and The Views URL1, URL2, URL8 & URL13.

2.3.1 Case Studies Climate and Analysis

According to (URL5,6 &7), the climate in Turkey is the same as the Mediterranean climate, where the summers are hot and dry while winter is mild and rainy. But Austria has a mainly continental climate, with warm, wet summers and cold, dry winters. While in The United Arab Emirates has an arid climate with very dry, hot, and humid summers and warm and dry conditions in winter. And Germany is part of the temperate, rainy climate zone of the mid-latitudes.

Table 2: Case studies analysis based on climate and typologies

Case studies countries	Climate		Typologies of AF
	Summer	Winter	
Turkey	Hot and dry	Mild and rainy	 Movable
Austria	Warm, wet	Cold, dry	 Responsive
Abu Dhabi	Dry, hot, and humid	Warm and dry	 Kinetic

Germany	Temperate, rainy climate zone	 Switchable
Germany		 Movable

The chapter has brought together the main findings on the adaptive facade and discussed various aspects of the AF (classification, construction system type, typologies, control, adaptive movement, and examples). And the evidence reviewed that there are three groups of facade classification (materials, components, and systems). And there are two types of facade system construction (load-bearing and non-load bearing), the control of Adaptive facade divided into (local and central) also AF movements into (simple and complex). Moreover, the typologies categorized into many types are active, advanced, biomimetic, kinetic, intelligent, interactive, movable, responsive**,** smart, switchable, and transferable). While in section two case studies, which are five cases in different four countries and different climate zones, case (1) in turkey is movable façade, case (2) Austria, responsive façade case (3) Abu Dhabi is kinetic façade, and case (4&5) in Germany switchable and movable respectively. However, according to the analysis of case studies above, the appropriate facade typologies that can be used in Northern Cyprus is movable façade because of used in Turkey, and as the data showed Turkey has the same as a Mediterranean climate.

Chapter 3

SUSTAINABILITY

This chapter about sustainability; focuses by focusing on sustainable development, then moving on to sustainable construction and finally, to sustainable building adaptive façade with environmental and economic dimension.

3.1 Sustainability

Sustainability means meeting our own needs without compromising the ability of future generations to meet their own needs. Moreover, to natural resources, we need social and economic resources. Sustainability is not just environmentalism. Embedded in most definitions of sustainability we should find concerns for social equity and economic development. "Brundtland Commission" released its final report, Our Common Future. It famously defines sustainable development as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Our Common Future, 2013). Sustainability is a holistic approach that considers ecological, social, and economic dimensions, recognizing that all must be considered together to find lasting prosperity (United Nations General Assembly, 2005). The three pillars/ dimensions of sustainability as shows in (Figure 20).

3.1.1 Environmental Sustainability

Ecological integrity is maintained in all of earth's environmental systems and is kept in balance while natural resources within them are consumed by humans at a rate where they can replenish themselves.

3.1.2 Economic Sustainability

Human communities across the globe can maintain their independence and have access to the resources that they require, financial and other, to meet their needs. Economic systems are intact, and activities are available to everyone, such as secure sources of livelihood.

3.1.3 Social Sustainability

Universal human rights and necessities are attainable by all people who have access to enough resources to keep their families and communities healthy and secure. Healthy communities have just leaders who ensure personal, labor, and cultural rights are respected and all people are protected from discrimination.

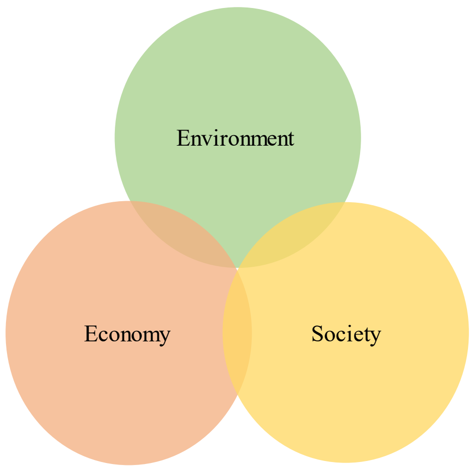

Figure 20: The Dimension of Sustainability (Lew, A.A. et. al., 2016).

3. 2 Sustainable Development

The definition of sustainability " to preserve the status quo and not disappear” (Sayer & Campbell, 2004). The following are descriptions of sustainability that come from the report of the Commission (Brundtland, 1987) "development that fulfills current demands without jeopardizing future generations' capacity to meet their own needs". However, Leach et al. define sustainability as "the ability to preserve particular elements of human well-being, social equality, and environmental integrity across time" (Leach, Stirling, & Scoones, 2010), based on these differences, (Lew et al.,

2016) define sustainable development as "Mitigating change while preserving and sustaining natural and cultural resources for the future". As well as addressing concrete initiatives of sustainability, such as "reducing carbon dioxide emissions, enhancing biodiversity, preserving tangible heritage artefacts, and revitalizing intangible cultural traditions".

Based on the above mentioned, sustainability is the preservation of resources for the future, in other words, to reduce the use of resources for the next generation to find them.

3. 3 Sustainable Construction

The term sustainable construction, as (Kibert, 1994.b); described in the conference, "build a healthy constructed environment according to resource-efficient, environmentally friendly principles". In the beginning, sustainable construction was merely concerned with the impact of limited natural resources, especially energy, and how construction could reduce its impact. Several years later, the focus was on technical issues: the environmental impact of appliances, building components, and construction technologies.

The principles for sustainability as it proposed to contain; reduces resource consumption, maximizing resource reuse, using renewable or recyclable resources, saving the natural environment, making a healthy non-toxic environment, applying life cycle analysis and real costs and quality follow-up in creating the built environment. As shows in (Figure 21).

Sustainable construction is becoming crucial because of concerns about harm to the environment caused by global warming was caused by climate change, and natural resources were depleted are agreed. It is more supported by fast economic expansion of many crowded cities globally, accounting for an expanding global environmental impact. The construction was rated as particularly important because of notable effects on the environment and the society that the built environment enhances the quality of life (Petri , L., et.al., 2014).

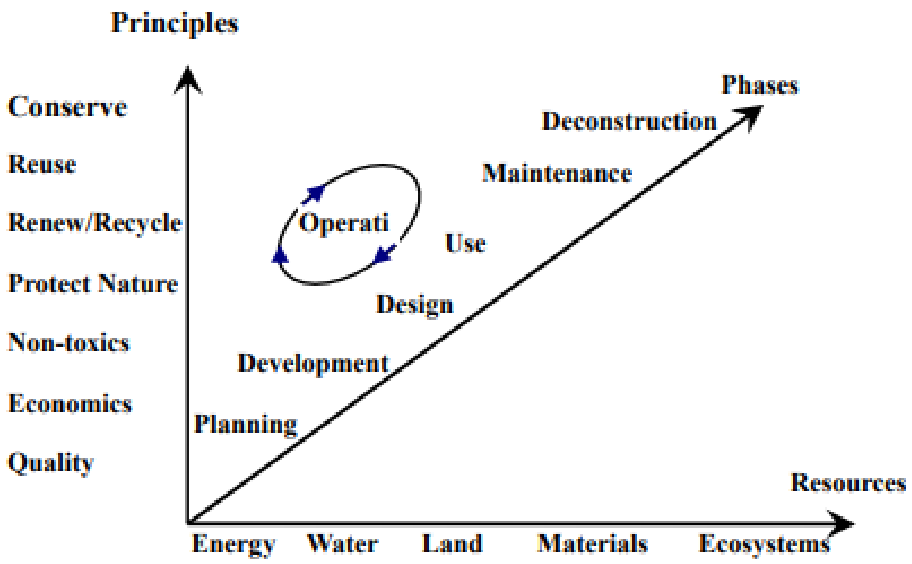

Figure 21: Sustainable Construction: Life Cycle Stages, Principles and Resources (Kibert, 1994.a).

3. 4 Sustainable Buildings - Adaptive Façade

For the sustainability of a facade, the design limit and the parameter for the potential sustainable model should be effectively considered. It will determine how the organisms heat, cool, provide shade and control light. The primary performance of the potentially defensible facade satisfied it significantly needs the energy requirements, procedure and structure, and sustainability consideration. In contrast, a facade is an external element of the building which, separate internal from the external environment. The envelope acts under the effects of on the indoor living and the changes in the climate conditions, which is the first criteria of a sustainable façade.

That usually defined as materials and energy efficiency, to achieve high performance in the façade consideration of using thermal, optical, airflow, and electrical mechanisms, while Aksamija defines sustainable façade helps in determine high-performance, as external cover that uses the least possible amount of dynamism to save a contented indoor environment, which enhances health and productivity of building users (Aksamija, 2013).

Energy Requirements

The essential common design that helps measure the sustainability reliability of the building energy if potentially demands the internal environment Regulation and condition ever the most effective energy that is used and the building is effective in need of heating or cooling down the materials. Effectively linked with the internal and external take with the facade. The potential organization depends on the weather conditions of 16 humidity is one of an essential components that is needed for building considering the most important of their respective technologies are used for thermal comfort for visual as well as production of renewable energy.

The constraints linked to heat and energy move are solar pollution, wind, and climate. The use of a façade is for current wellbeing changes; based on the characteristics and chunkiness of the layers of the material, moreover, to heat balance on the component envelope cause to the materials and properties.

The level of graphic luxury relies on the quantity of bright required, the amount of glare, the amount of sunny broadcast, the color of clearness, and the number of reflections caused by the internal sunny program and internal lighting. The façades are coming generators of renewable energy. The main energy reserve on the earth is photosynthesis. In comparison, glass systems that respond to light, electricity, and heat exist, (Dahl, 2013).

Sustainable Consideration

The previous scientific research argues that carbon emissions from humans' cause damage to the environment which, is global warming. So far, nature uses carbon as a building element of living organisms; the fundamental issue of architectural processes is to use the optimum number of resources and thus how to reduce environmental neither high temperatures nor toxicity (Benyus JM, 2002), from different points, human-made environment fully depends on outside energy resources, the primary, energy sources of nature which are the sun and gravity. Nature provides many notions to assist us with a more sustainable lifestyle in this way. The façade gives several considerations, which: air quality, water efficiency, carbon capture, utilization of non-toxic materials, low embodied energy, low materials use, biological behavior, responsiveness, adaptability, and sense. Moreover, photosynthesizing façade allows for capturing carbon from the environment, whereas making more air to breathe than breathing could be by planting greenery (green space) regulates Heat, air, water, and electricity are all used to improve the efficiency of green spaces. Indoor air quality is linked to health and productivity difficulties in buildings, in addition to thermal comfort (Forouzanfar et al., 2015).

2. 4. 1 Environmental Dimension

The environmental dimension for an adaptive façade is to make a comfortable environment by vigorously answering to building outdoor heaven and significantly diminishing building energy ingesting. And climate how to consider during design processes of high-performance enclosures (Oral, G., Yener, A. & Bayazit, N., 2004).

There are characteristics of an energy-efficient, sustainable building for a façade. Which are: access daylight into the building, stores heat within the mass of the wall, block heat transfer via enhanced insulation, from façade access are moisture with prevent air and natural freshening to cool the enclosed buildings. And the properties are relied on climate, building function, users' patterns, orientation, tools load, and façade typologies (Lee. et.al. 2002).

The environmental dimension for the adaptive façade system explains the possibility of using renewable resources. The adaptive facade covers environmental dimension factors; natural ventilation, thermal comfort, daylight/ visual comfort, and the orientation of the building/ facade.

3.4.1.1 The Orientation of the Buildings/ Façade

The direction of the building specified its contact to sunshine, can advantage from the direct solar energy in the building in cold weather during the winter season, on the other hand, hot climate need to shade spaces from direct sunlight and solar radiation. Whereas optimum positioning of the building solar energy is the balance of solar heat gains in winter with shading in the summer season, because of the passive effect of the solar direction of the façade, which should be considered in the early design stages, that effect on the amount of direct solar radiation and light.

3.4.1.2 Thermal Comfort

Improving the thermal presentation of building façade and reducing thermal bridging that is curial for sustainable strategies and a wall is thermal by bridged when a highly conductive material, such as metal support, penetrates the façade wadding layers, this can be the effect on the thermal of the walls and reduce the impact of thermal resistance (Lawton, M. et.al, 2010).

The heat transfer through the facade depends on the differences in temperature between inside – outside and the ability of the façade performance to control heat flow and the effect of the factors on heat flow in façade and overall thermal resistance, materials characteristic and air lack control (Aksamija, 2015).

3. 4.1.3 Daylight and Visual Comfort

The façade plays a primary role in the amount of light entering the building by blocking and distributing direct glare by reflecting and distributing thus providing a comfortable visual to users (Tabadkani, A. , Roetzel, A. Xian Li, H. & Tsangrassoulisb, A., 2021). Moreover, the windows and opening size affect the amount of light access. Control in lighting access and visual in adaptive façade depending on adaptive facades typologies and the number of layers. The control works accordingly to climate conditions and requirements of the occupant (Brzezicki, 2021).

3.4.1.4 Natural Ventilation

Natural ventilation plays an essential function in the building. Achieving it is not easy; so far, it needs to consider from the first stages of design. A façade has a significant effect in achieving natural ventilation in the buildings and is also considered one of the facade functions (Mahdavinejad, M. & Mohammadi, S., 2018). This means that can happen in the gap between two layers in the façade, sometimes used as a shaft for ventilation there is a high-pressure zone which is for entering the fresh air and through the exhausted air, in other words, for exchanging the air. From an energy demand perspective, the layers separate the buildings and block the heat to access to the building thus, leading to no need for more energy for heating/cooling for the indoor environment. The façade is a building element and effective from wall to windows, the opening size and windows provide air into the building and effective the insulation of indoor spaces (Yüksek,I. & Karadayi,T., 2017).

3.4.2 Economic Dimension

The economic dimension of the adaptive facade or the façade system is related to issues associated with the principles economic of adaptive façade, and that includes the lifecycle of the façade and all operational maintenance costs; to achieve this dimension should be noticed since facade design in early stage and the different parameters related to the use of the building and location.

3.4.2.1 The Life Cycle of Façade

In general, buildings have been using different materials resources in the building elements have different life cycles (Brand, 1994). Explained with shearing layers of change, that façades have a life span of more than 20 years; in contrast, this is somehow like the main building structure, which is known from 30-300 years ago. Façade could have a lower life span with contributing at least 20% of the cost of buildings (Parker, Wood, 2013)**.** The technical life cycle of the façade impact with chosen materials in the first stage of the façade design and the technical design participate to 80% of the environmental impact of the building (Morinia, A.,Ribeirob,M. & Hotzac, D., 2019). Facades have such effects on the operational energy and aesthetic imprint**.**

Adaptive façade components act on an extrinsic stimulus with low environmental impact and at an affordable price. The durability and life cycle of the element are fundamental to the future of the application. The function of the component façade does not shorten inefficiency in energy exhaustion (Aelenei, L., et al. 2018, p. 55).

According to a report published by (Alba concepts, 2020), which addressed the possibilities of producer responsibility for façade, with short life cycles of facades can be supposed to replace every existing Aluminum façade every 75years later. These main that the life span of some materials is different from the other which some of them the life span are long and some short so far can apply for any kind of, materials now but, the question is will work for or have the same function for today, because the technologies are updated.

2.4.2.2 Operational and Maintenances Cost

From the standpoint of materials and components are those materials that are either completely new or old ones that are put to reuse in construction components (Couto, A. & Couto, P. J., 2010). On the other hand, from an economic perspective, typically, a first investment involves cost and is required to perform adaptive components; in this case, a comprehensive analysis of cost-benefit largely unfulfilled requires empirical evidence and existing features considering the whole cost of life cycle (Cadenas. F. M., Javier. F. & Neila. J. 2015).

While the cost of an adaptive façade technologies system is complex and expensive compared to the traditional one. Still, it is to resolve the consumption of an extensive amount of energy and attain energy productivity. The idea of the operation of AF to less service installing and mechanical service system in the building is improving the characteristics of the AF system as in the previous studies.

It is not limited to energy-saving is about installing type, duration operations, maintenance, and which type are used to maintain. The maintenance cost depends on the typologies of AF and the sizes of the façade, and some typologies do not need maintenances.

The chapter has brought together and discusses the sustainability part the energy requirement, system consideration of adaptive facade and environmental dimension factors (natural ventilation, thermal comfort, daylight/ visual comfort, and the orientation of the building façade, moreover, discuss economic dimension through the life cycle of façade and maintenances operational cost. The coming chapter evaluation the adaptive facade in Northern Cyprus conditions and discuss the possibility of the adaptive facade in Northern Cyprus colored building EMU Faculty of Architecture as a case study.

Chapter 4

EVALUATION FAÇADE ADAPTIVITY IN NORTHERN CYPRUS

4.1 Northern Cyprus Condition

Cyprus is the third largest island in the Eastern Mediterranean Sea, is significantly located 33° E, 35° N, as shown in (Figure 22). The island is divided into two parts; the northern part belongs to the Turkish Republic and, the southern part belongs to Greece. It has a Mediterranean climate that has minor winters dry summers (Michaelides & Votsi, 1991).

In the eastern part of the island, Famagusta locates on average; the city is 25 meters above sea level. Its geographical position is 35.1 ° N, 33.9 ° E. moreover, it has a warm Mediterranean climate and mild/moderate seasons (Kottek, 2006). In the summer, the humidity is extremely high, making the heat unbearable (Figure 23). Nevertheless, it should not forget that the absorption rate of energy is different from that of heat-induced moisture (Oktay, 2009).

Figure 22: Cyprus Geographical Map URL11

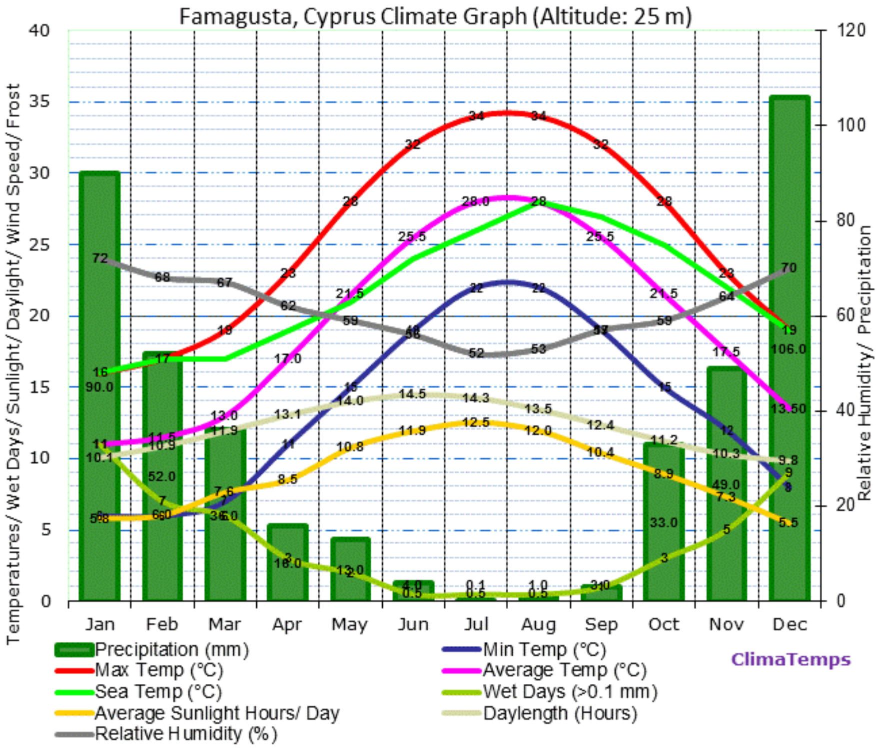

Figure 23: The Annual Geographical Famagusta Climate URL12

4.2 Case Study

4.2.1 Faculty of Architecture EMU/ Colored Building

A case study is a multi-story educational building and is one of the buildings of faculty architecture in Eastern Mediterranean University (EMU) as shows in (Figure 4.3). To the evaluate the adaptivity of solar facade under Northern Cyprus conditions to generate energy.

The colored building is rectangular (30° to N and 60 °to E). It consists of three floors: (ground floor which including: (studios for architectural students, a library, seminar room, exhibition area, and cafeteria) whereas the first and second floors are typical that including studios for architecture. The building hours working 24/7 five days per week during three semesters (Fall, spring, and summer). The building has HVAC system air conditions with separate units indoor and outdoor. The survey shows that all facades of building surrounded by trees except Northeast facade as shown in (Figure 24).

Figure 24: Faculty of Architecture in EMU Campus (From Google Earth, 2022)

Figure 25: Show Colored Building Façades 1) Northwest façade 2) Northeast Façade 3) Southeast Façade and 4) Southwest Façade. Taken By the Author.

4.2.2 Survey/ Observation Result

The building is surrounded by trees from all directions except the Northeast direction. And these trees made some shade and blocked the direct sun on the buildings. The windows used in a building have different size windows. In the indoor, use the curtain to control the amount of sunlight and lighting in the interior space. Based on the result of the observation above, the researcher decided to adopt a movable facade that integrated PV into shading, the shading used in this research is horizontal and vertical shading in southwest and northwest facades, and after that to analysis and calculation then compering between two horizontal and vertical to ensure the workability of PVs.

According to observation and analysis in previous sections above the facade is movable façade which is made of aluminum panels with solar PV panels attached to it for generate energy, the aluminum panels move according to angle of open as blinds and the control manual. In this case using vertical aluminum panels and horizontal aluminum panels to see workability of each one is more efficient.

4.2.3 PV Dimension and Calculations

4.2.3.1 Dimension

Table 3: Component materials, (Modeling, 2016).

Cell per module	72
Cell type	Polycrystalline
Cell dimensions	2.04in × 6.14in (52mm×156mm)
Front	Tempered glass (EN12150)
Frame	Clear anodized aluminum
weight	17.6lbs (8.0 kg)

Table 4: Performance under standard test condition (STC), (Modeling, 2016).

Maximum power P_{max}	100 WP
Open circuit voltage V_{oc}	44.2 V
Maximum power point Voltage V_{mpp}	37.6 V
Short circuit current I_{sc}	3.02 A
Maximum power point Current I_{mpp}	2.75 A
Module efficiency η_m	13.61 %

4.2.3.2 Calculation

(Figure 26) shows the concept of PVs panel in one row as calculation

To calculate the area of PV cell from the dimension above

52mm× 156mm= 8112mm^2.

The active area= the total of PV cell area × cells per module

= 8112mm2 × 72= 584064/ 106 = 0.584064m^2.

For Southwest Horizontal:

In one row, have 13 panels of PV connected in series, and there are six rows in facade

So, to calculate the active area for one row = active area of one PV module is 0.584064m2 × the number of the unit array in the row 13 panels

0.584064m2 ×13= 7.59 6m^2

Northwest Horizontal

In one row, have 25 panels of PV connected in series, and there are six rows in facade

So, to calculate the active area for one row = active area of one PV module is 0.584064m2 × the number of the unit array in the row 25 panels

$0.584064m^2 \times 25 = 14.6016m^2$

For Southwest Vertical

In one row, have 11 panels of PV connected in series, and there are six rows in facade

So, to calculate the active area for one row = active area of one PV module is 0.584064m2 × the number of the unit array in the row 11 panels

$0.584064m^2 \times 11 = 6.424704\ m^2$

For Northwest Vertical

In one row, have 22 panels of PV connected in series, and there are six rows in facade

So, to calculate the active area for one row = active area of one PV module is 0.584064m2 × the number of the unit array in the row 22 panels

$0.584064m^2 \times 22 = 12.85\ m^2$

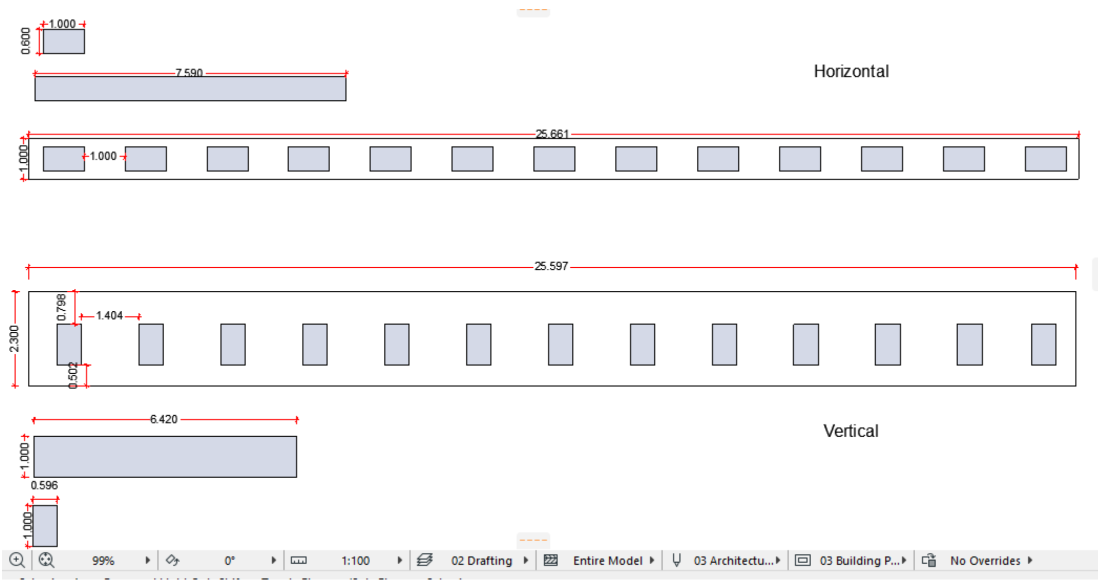

Figure 26: Shows the Concept of the Composed of PVs Modules in One Row as Vertical and Horizontal SW and NW, ©ArchiCAD, by Author.

4. 3 Simulation Software: Design Builder-Energy Plus

Design Builder is the most established and advanced user interface to Energy Plus. The author used Design Builder software to simulate the colored building by calculating energy use in the colored building before integrating PV into the façade by calculated system load and the overall building energy use. The calculation in design-builder according to a database of design-builder and the simulation run from January to December. And calculate energy generation for the Northeast façade by integrating PV into horizontal shading as movable façade, the movement of façade moving according to climate condition and the control is manual.

4. 3. 1 The Result and Discussion of Simulation

4.3.1.1 The Simulation Result of Colored Building EMU Before Shading and Integrated PV Panels on Facade

Table 5: Electric loads satisfied without PV © Energy plus (4month)

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	0.000	0.00
Wind power	0.000	0.00
Power conversion	0.000	0.00
Net decrease in on-site storage	0.000	0.00
Total on-site electric sources	0.000	0.00
Electricity coming from utility	268272.080	100.00
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	268272.080	100.00
Total on-site and utility electric sources	268272.080	100.00
Total electricity end uses	268272.080	100.00

Table 6: Electric loads satisfied without PV © Energy plus (12month)

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	0.000	0.00
Wind power	0.000	0.00
Power conversion	0.000	0.00
Net decrease in on-site storage	0.000	0.00
Total on-site electric sources	0.000	0.00

Electricity coming from utility	656514.436	100.00
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	656514.436	100.00
Total on-site and utility electric sources	656514.436	100.00
Total electricity end uses	656514.436	100.00

4.3.1.2 The Simulation Result of Colored Building EMU After Integrated PV Panels on Façade

Table 7: Electric loads satisfied © Energy plus (4 months) horizontal shading and PV on SW façade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	4183.974	1.71
Wind power	0.000	0.00
Power conversion	-167.36	-0.1
Net Decrease in On-Site Storage	0.000	0.00
Total on-site electric sources	4016.615	1.64
Electricity coming from utility	240477.782	98.36
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	240477.782	98.36
Total On-Site and Utility Electric Sources	244494.398	100.00
Total electricity end uses	244494.398	100.00

Table 8: Electric loads satisfied © Energy plus (12 months) horizontal shading and PV on SW façade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	10507.715	1.74
Wind power	0.000	0.00
Power conversion	-420.31	-0.1
Net Decrease in On-Site Storage	0.000	0.00
Total on-site electric sources	10087.406	1.67
Electricity coming from utility	595093.935	98.33
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	595093.935	98.33
Total On-Site and Utility Electric Sources	605181.341	100.00
Total electricity end uses	605181.341	100.00

Table 9: Electric loads satisfied © Energy plus (4 months) horizontal shading and PV on NW facade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	6077.803	2.45
Wind power	0.000	0.00
Power conversion	-243.11	-0.1
Net Decrease in On-Site Storage	0.000	0.00
Total on-site electric sources	5834.690	2.35
Electricity coming from utility	242488.065	97.65
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	242488.065	97.65

Total On-Site and Utility Electric Sources	248322.756	100.00
Total electricity end uses	248322.756	100.00

Table 10: Electric loads satisfied © Energy plus (12months) horizontal shading and PV on NW facade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	13599.237	2.22
Wind power	0.000	0.00
Power conversion	-543.97	-0.1
Net Decrease in On-Site Storage	0.000	0.00
Total on-site electric sources	13055.267	2.13
Electricity coming from utility	599729.800	97.87
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	599729.800	97.87
Total On-Site and Utility Electric Sources	656514.436	100.00
Total electricity end uses	612785.067	100.00

Table 11: Electric loads satisfied © Energy plus (4months) vertical shading and PV on SW facade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	1371.012	0.56
Wind power	0.000	0.00
Power conversion	-54.84	-0.0
Net Decrease in On-Site Storage	0.000	0.00

Total on-site electric sources	1316.171	0.54
Electricity coming from utility	242986.331	99.46
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	242986.331	99.46
Total On-Site and Utility Electric Sources	244302.503	100.00
Total electricity end uses	244302.503	100.00

Table 12: Electric loads satisfied © Energy plus (12months) vertical shading and PV on SW facade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	3375.334	0.56
Wind power	0.000	0.00
Power conversion	-135.01	-0.0
Net Decrease in On-Site Storage	0.000	0.00
Total on-site electric sources	3240.320	0.54
Electricity coming from utility	601544.890	99.46
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	601544.890	99.46
Total On-Site and Utility Electric Sources	604785.211	100.00
Total electricity end uses	604785.211	100.00

Table 13: Electric loads satisfied © Energy plus (4months) vertical shading and PV on NW facade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	1760.493	0.71
Wind power	0.000	0.00
Power conversion	-70.42	-0.0
Net Decrease in On-Site Storage	0.000	0.00
Total on-site electric sources	1690.073	0.68
Electricity coming from utility	246359.190	99.32
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	246359.190	99.32
Total On-Site and Utility Electric Sources	248049.264	100.00
Total electricity end uses	248049.264	100.00

Table 14: Electric loads satisfied © Energy plus (12months) vertical shading and PV on NW facade

	Electricity [kWh]	Percent Electricity [%]
Fuel-fired power generation	0.000	0.00
High temperature geothermal*	0.000	0.00
Photovoltaic power	3637.704	0.59
Wind power	0.000	0.00
Power conversion	-145.51	-0.0
Net Decrease in On-Site Storage	0.000	0.00
Total on-site electric sources	3492.196	0.57
Electricity coming from utility	608153.451	99.43
Surplus electricity going to utility	0.000	0.00
Net electricity from utility	608153.451	99.43

Total On-Site and Utility Electric Sources	611645.647	100.00
Total electricity end uses	611645.647	100.00

4.3.2.3 Result and Discussion

According to (Tables 6,8,10,12 & 14) from energy plus simulation the result of total electricity end-use in colored building EMU is 656514.436kwh for all year. And total energy end uses for electricity when adapting horizontal shading and PVs in the Northwest façade was 612785.067 kwh, which is reduced from an amount above about 43729.369kwh. While totals energy end uses for electricity when adapting horizontal shading and PVs in Southwest façade it was 605181.341kwh this means that the horizontal shading and PV can offer around 5133.095kwh. The total energy end uses in CB when integrated vertical shading and PV in northwest façade it was 611645.647kwh, and energy can be given around 44868.789kwh.

Consecutively, to (Tables 5,7,9,11&13) simulation run from June to September according to energy plus simulation the total electricity end-use in CB is 268272.080kwh. And total energy when integrated horizontal shading and PV in the SW façade is 24494.398kwh, the total energy is reduced by about 23777. 682kwh.Whereas, the total energy uses in CB when integrated horizontal shading and PV on NW façade was 248322.756kwh, and energy can gain from it is 19949.324. But the total when integrated vertical on SW façade was 244302.503kwh, which means that energy can produce for vertical shading SW is 23969.577kwh. However, the NW façade from vertical shading and PV panels when integrated totals use energy is 248049.264kwh which the reduction was around 20222.816kwh.

The result shows that southwest façade vertical and horizontal shading and PV are more effectively than northwest vertical and horizontal 51729.225kwh, 51333.095kwh, 44868.789kwh and 43729.369kwh respectively.

Chapter 5

CONCLUSION

The study is evaluation façade adaptivity in the context of sustainable building in Northern Cyprus, the city of Famagusta, and the case study was one of the buildings of Faculty of architecture in EMU (colored building) by integrating PV into vertical and horizontal façade to generate electricity to the building.

Generally, this study analyzed and evaluated façade adaptivity in Northern Cyprus. The author studies and analyses the adaptive facade typologies and clarifies which topologies are appropriate to adapt in Northern Cyprus. Then observation and survey the case study the colored buildings in the EMU faculty of architecture; the survey showed that the outdoor condition of CB, therefore, the most façades are surrounded by trees southwest, southeast, and northwest, except northeast façade there are no trees. Generally, the case study is an educational building and consists of three floors: are ground, first, and second is typical floors.

The simulation was on Southwest façade and Northwest façade in horizontal level and vertical level for whole year and for four months (June to September). The result shows that southwest façade vertical and horizontal shading and PV are more effectively than northwest vertical and horizontal 51729.225kwh, 51333.095kwh, 44868.789kwh and 43729.369kwh respectively.

The energy that can be produced after integrated PV panels in horizontal shading and PV in the southwest and northwest façades is 95062.464kwh. The energy that can be produced after integrated PV panels in vertical shading in the southwest and northwest façades is 96598.0144kwh. this mean that southwest façade vertical and horizontal shading and PV are more effectively than northwest vertical and horizontal.

5.1 Recommendations

The current assessment has been carried out within the limitations of the case study, there; are some recommendations for the future:

Further studies of shading devices for the window can be facade windows for shade or automated glazing for generation energy.

More study on adaptive facade better performance in the Northern Cyprus in terms of energy efficiency. And appropriate facade types could be active, movable, switchable, and responsive these are more efficient but, the other typologies will work but are not sustainable.

Deep study on chromogenic glazing facade for window will provide comfort visual and block unwanted light and glare.

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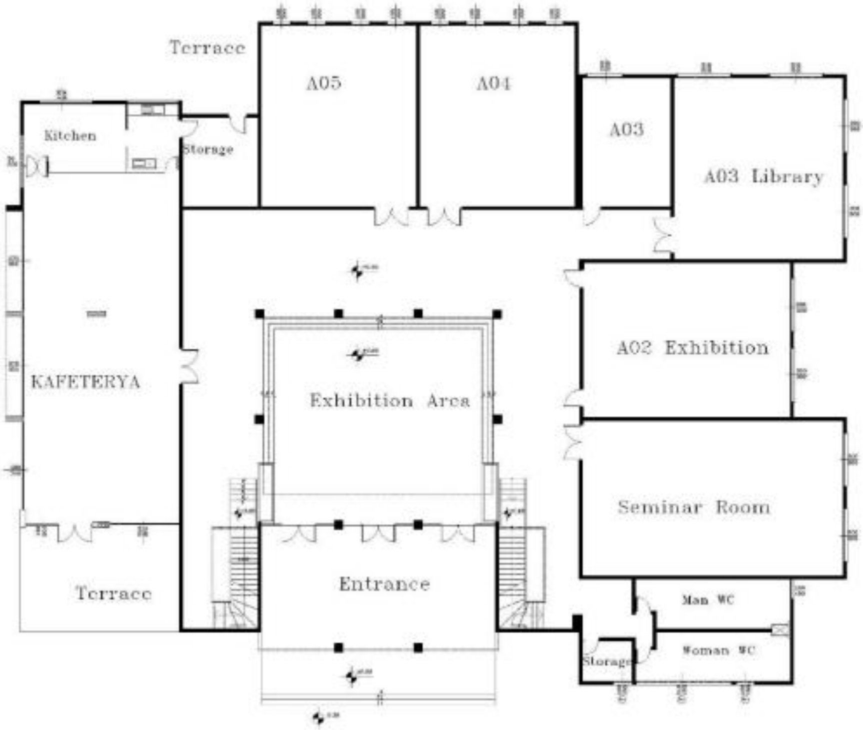
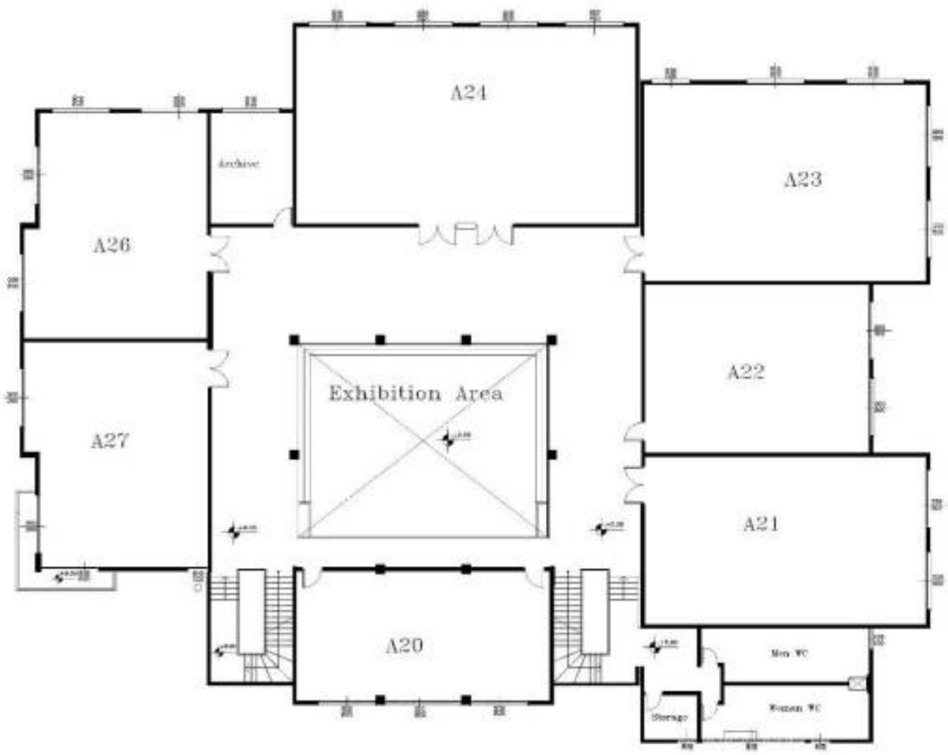
APPENDICES

Appendix A: Colored Building EMU Plans



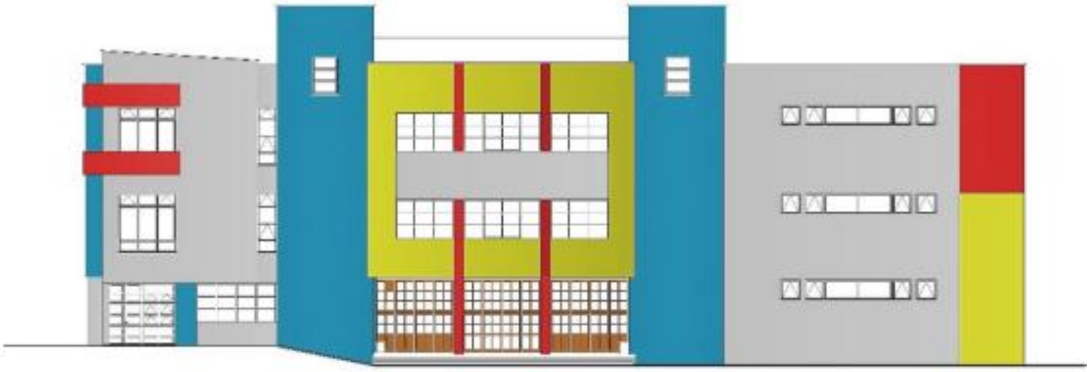
Ground Floor Colored Building



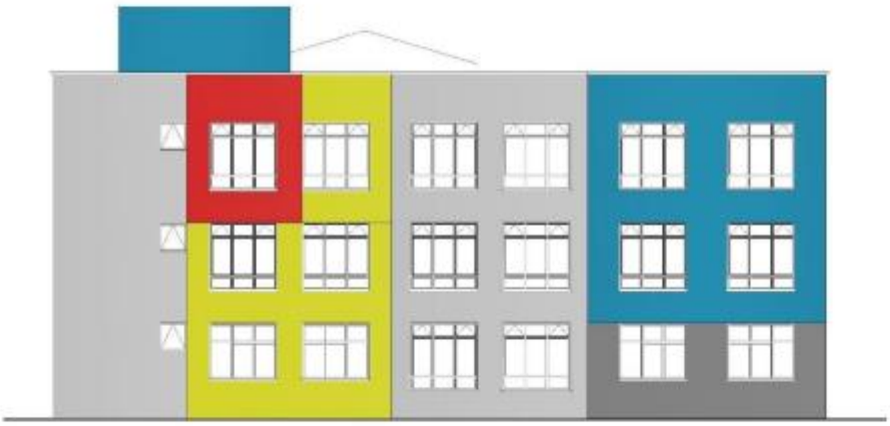
First + Second Floor Colored Building

Appendix B: Colored Building EMU Façades/Elevations

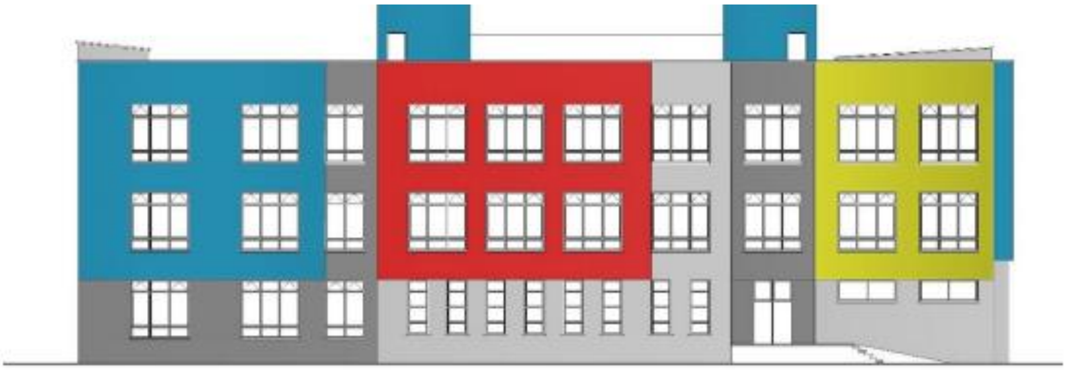
South-west Façade



South-east Façade



North-East Façade



North-West Façade

Appendix C: Sun Module Off-grid 100 Poly RGP Solar Panel Data Sheet / Solar World


Sunmodule
SW 100 POLY RGP

SOLARWORLD
REAL VALUE

TUV Power controlled:
Lowest measuring tolerance in industry

25-year performance warranty
and 5-year product warranty

World-class quality
Fully-automated production lines and seamless monitoring of the process and material ensure the quality that the company sets as its benchmark for its sites worldwide.

Resistant to extreme weather conditions. SolarWorld modules are tested and certified resistant against sandstorms, high winds and costal environments.

*in accordance with the applicable SolarWorld Limited Warranty at purchase
www.solarworld.com/warranty

UL 1703

ISO 9001
ISO 14001
Certified

Sunmodule®

SW 100 POLY RGP

SOLARWORLD
REAL VALUE

PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

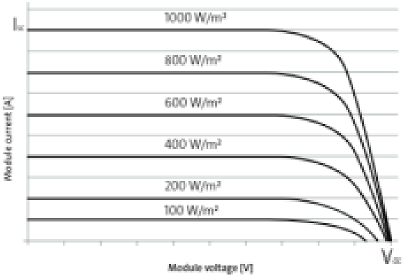
Maximum power	P_{max}	100 Wp
Open circuit voltage	V_{oc}	44.2 V
Maximum power point voltage	V_{mpp}	37.6 V
Short circuit current	I_{sc}	3.02 A
Maximum power point current	I_{mpp}	2.75 A
Module efficiency	η_m	13.61 %

*STC: 1000 W/m², 25 °C, AM 1.5

1) Measuring tolerance (P_{max}) traceable to TUV Rheinland: +/- 2% (TUV Power Controlled).

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I_{sc}	0.051 % / °C
TC $_{Voc}$	-0.31 % / °C
TC P_{mpp}	-0.41 % / °C
Operating temperature	-40 to +85 °C



PERFORMANCE AT 800 W/m², NOCT, AM 1.5

Maximum power	P_{max}	72.7 Wp
Open circuit voltage	V_{oc}	38.9 V
Maximum power point voltage	V_{mpp}	33.1 V
Short circuit current	I_{sc}	2.46 A
Maximum power point current	I_{mpp}	2.20 A

Minor reduction in efficiency under partial load conditions at 25 °C: at 200 W/m², 100% (+/-2%) of the STC efficiency (1000 W/m²) is achieved.

COMPONENT MATERIALS

Cells per module	72
Cell type	Polycrystalline
Cell dimensions	2.04 in x 6.14 in (52 mm x 156 mm)
Front	Tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	17.6 lbs (8.0 kg)

SYSTEM INTEGRATION PARAMETERS

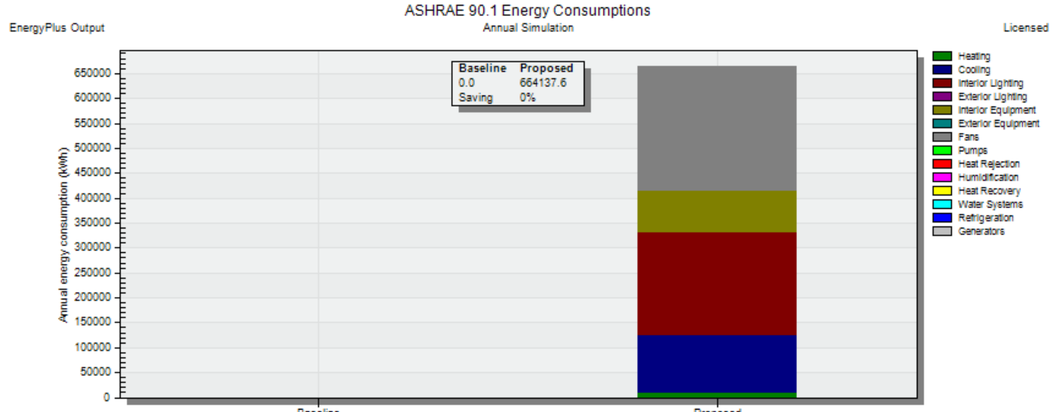
Maximum system voltage SC II		1000 V
Maximum system voltage NEC		600 V
Maximum reverse current		15 A
Number of bypass diodes		2
*Design Loads**	*Two rail system*	113 psf downward 50 psf upward

* Please refer to the Sunmodule installation instructions for the details associated with these load cases.

ADDITIONAL DATA

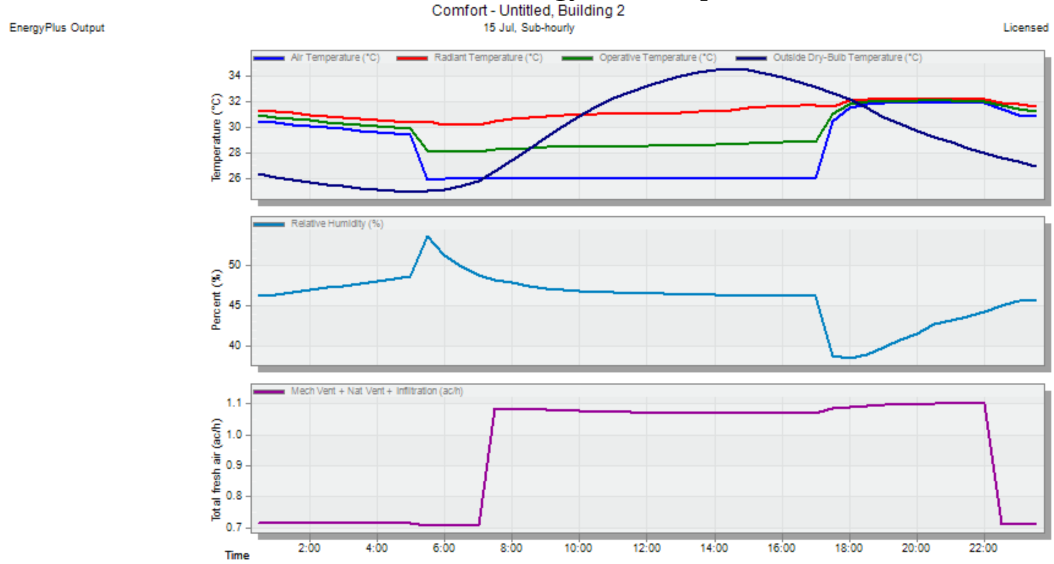
Power sorting	+/- 10 %
J-Box	IP65
Module type (UL 1703)	1

Appendix D: Colored Building Simulation Before Integrated PV from (January -December)



	Baseline	Proposed
Heating	0.00	7623.17
Cooling	0.00	116540.69
Interior Lighting	0.00	206942.05
Exterior Lighting	0.00	0.00
nterior Equipment	0.00	81599.31
xterior Equipment	0.00	0.00
Fans	0.00	251432.38
Pumps	0.00	0.00
Heat Rejection	0.00	0.00
Humidification	0.00	0.00
Heat Recovery	0.00	0.00
Water Systems	0.00	0.00
Refrigeration	0.00	0.00
Generators	0.00	0.00

ASHEAR 90.1 Energy Consumption



Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Air Temperature (°C)	30.09	29.62	25.99	26.01	26.01	26.01	26.01	26.01	31.49	31.90	31.88
Radiant Temperature (°C)	30.97	30.53	30.20	30.63	30.97	31.03	31.27	31.63	32.10	32.16	32.15
Operative Temperature (°C)	30.53	30.08	28.09	28.32	28.49	28.52	28.64	28.82	31.79	32.03	32.02
Outside Dry-Bulb Temperature (°C)	25.67	25.09	25.09	27.40	30.85	33.25	34.50	33.92	32.20	29.70	27.97
Relative Humidity (%)	46.97	48.09	51.26	47.85	46.80	46.53	46.32	46.16	38.43	41.54	44.31
lech Vent + Nat Vent + Infiltration (ac/h)	0.71	0.71	0.71	1.08	1.08	1.07	1.07	1.07	1.09	1.10	1.10

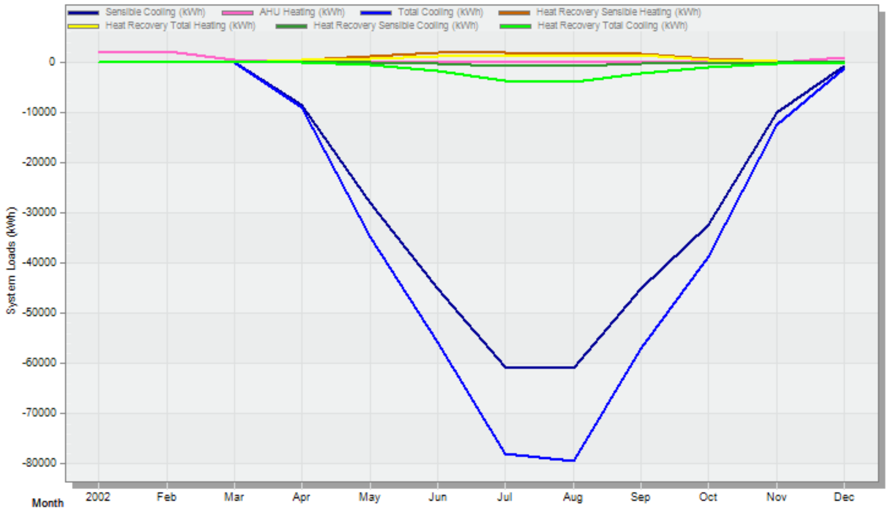
Cooling Load

EnergyPlus Output

New Result Set without PV - Untitled, Building 2

1 Jan - 31 Dec, Monthly

Licensed



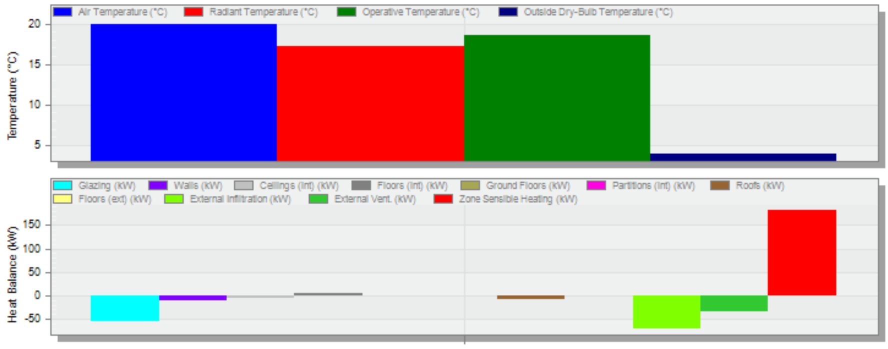
Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sensible Cooling (kWh)	-1.46	-13.10	0.00	-8496.56	-27949.78	-45016.61	-60742.16	-61017.27	-45029.59	-32406.64	-10102.27	-819.32
AHU Heating (kWh)	1982.12	2136.02	594.15	128.75	2.22	51.09	55.47	55.03	31.49	1.98	28.99	1031.23
Total Cooling (kWh)	-2.41	-14.77	0.00	-8940.30	-34736.23	-55768.60	-77973.39	-79353.54	-56962.96	-38764.75	-12446.44	-1216.40
Heat Recovery Sensible Heating (kWh)	0.00	0.00	0.00	378.03	1310.46	1880.88	1849.63	1723.49	1748.59	776.39	211.93	20.50
Heat Recovery Total Heating (kWh)	0.00	0.00	0.00	365.82	757.06	1288.90	1396.81	1222.95	1393.90	531.01	126.92	13.95
Heat Recovery Sensible Cooling (kWh)	0.00	0.00	0.00	-23.23	-22.83	-261.23	-646.54	-763.24	-306.74	-208.47	-37.34	0.00
Heat Recovery Total Cooling (kWh)	0.00	0.00	0.00	-28.11	-560.25	-1726.42	-3630.84	-3949.83	-2212.44	-1018.40	-305.92	-0.01

System Load

Temperature and Heat Loss

EnergyPlus Output

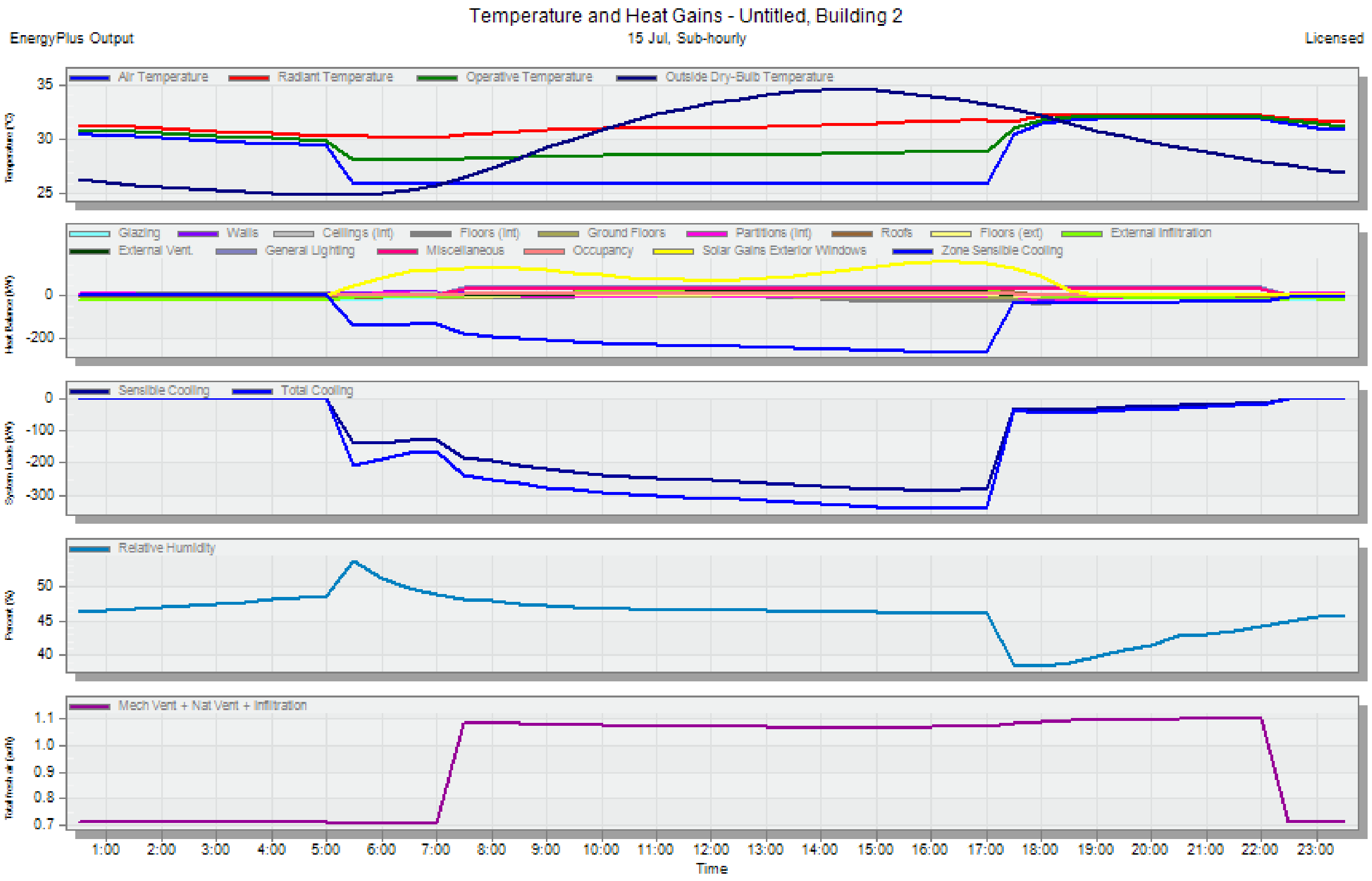
Licensed



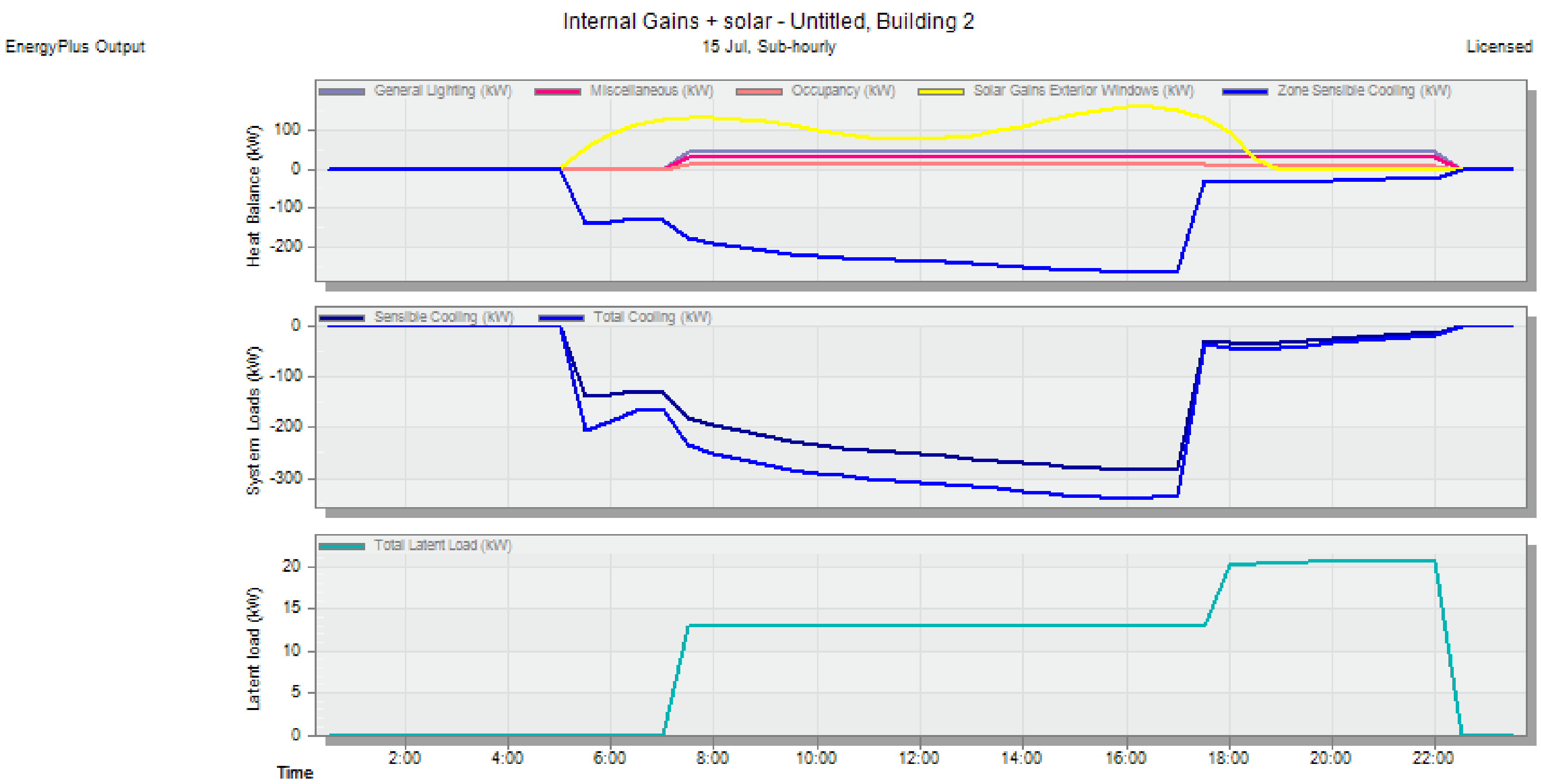
Air Temperature (°C)	19.97
Radiant Temperature (°C)	17.23
Operative Temperature (°C)	18.60
utside Dry-Bulb Temperature (°C)	3.90
Glazing (kW)	-55.48
Walls (kW)	-11.17
Ceilings (int) (kW)	-4.39
Floors (int) (kW)	4.39
Ground Floors (kW)	0.06
Partitions (int) (kW)	0.00
Roofs (kW)	-8.77
Floors (ext) (kW)	-0.94
External Infiltration (kW)	-69.78
External Vent. (kW)	-35.15
Zone Sensible Heating (kW)	181.23

Heat load losing

Appendix E: Colored Building Simulation Before Integrated PV from (June-September)

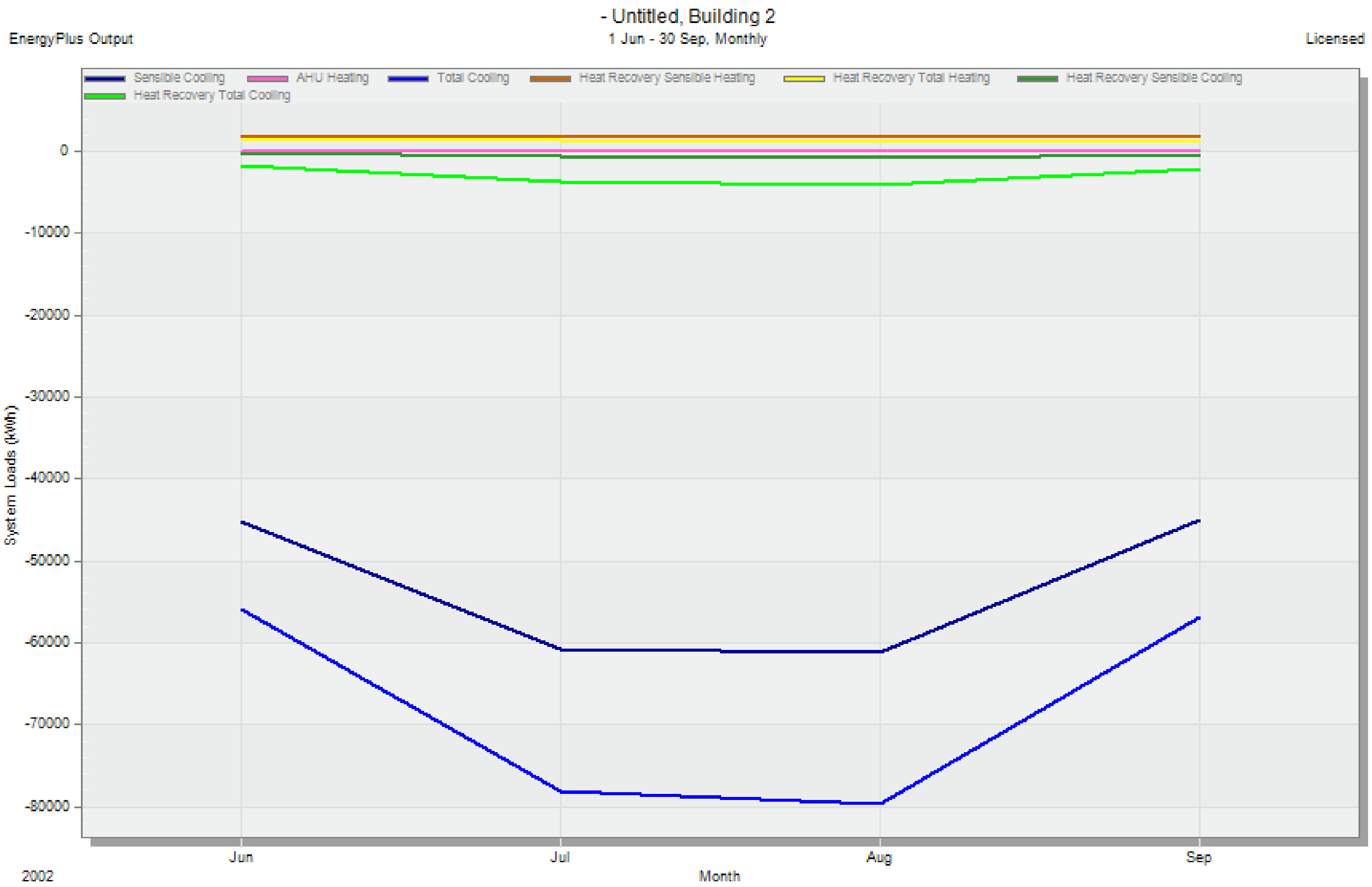


Cooling System Load of Colored Building



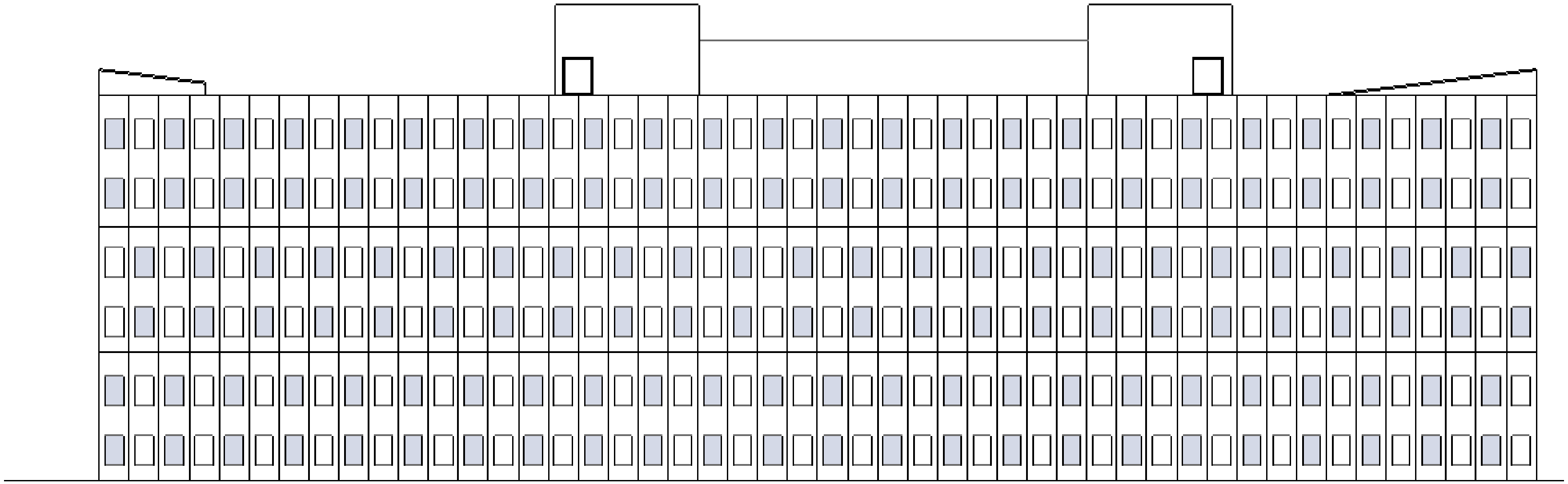
General Lighting (kW)	0.00	0.00	0.00	43.84	43.84	43.84	43.84	43.84	43.84	43.84	43.84
Miscellaneous (kW)	0.00	0.00	0.00	31.32	31.32	31.32	31.32	31.32	31.32	31.32	31.32
Occupancy (kW)	0.00	0.00	0.00	13.37	13.37	13.37	13.37	13.37	6.23	5.78	5.79
olar Gains Exterior Windows (kW)	0.00	0.00	89.40	132.17	99.80	75.07	111.23	159.32	92.79	0.00	0.00
Zone Sensible Cooling (kW)	0.00	0.00	-136.85	-191.12	-223.80	-236.90	-251.80	-265.76	-34.23	-30.77	-23.61
Sensible Cooling (kW)	0.00	0.00	-136.85	-194.37	-234.78	-253.24	-270.92	-283.60	-34.51	-25.90	-14.85
Total Cooling (kW)	0.00	0.00	-190.33	-250.95	-289.76	-308.05	-326.66	-339.35	-44.56	-34.69	-19.96
Total Latent Load (kW)	0.00	0.00	0.00	12.93	12.93	12.93	12.93	12.93	20.06	20.51	20.51

Internal gains & solar

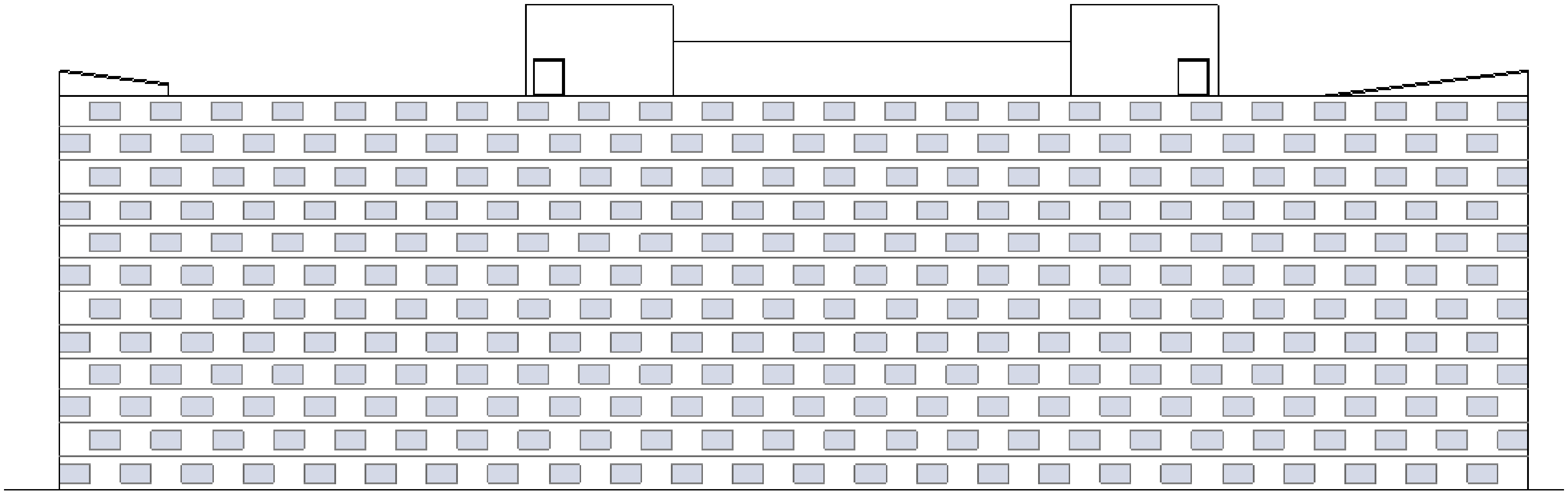

- Untitled, Building 2
EnergyPlus Output
1 Jun - 30 Sep, Monthly
Licensed
Sensible Cooling
AHU Heating
Total Cooling
Heat Recovery Sensible Heating
Heat Recovery Total Heating
Heat Recovery Sensible Cooling
Heat Recovery Total Cooling
System Loads (kWh)
0
-10000
-20000
-30000
-40000
-50000
-60000
-70000
-80000
Jun
Jul
Aug
Sep
2002
Month

System Load

Appendix F: The Concept of Shading and Integrated PV on The Northwest Façade Vertical and Horizontal

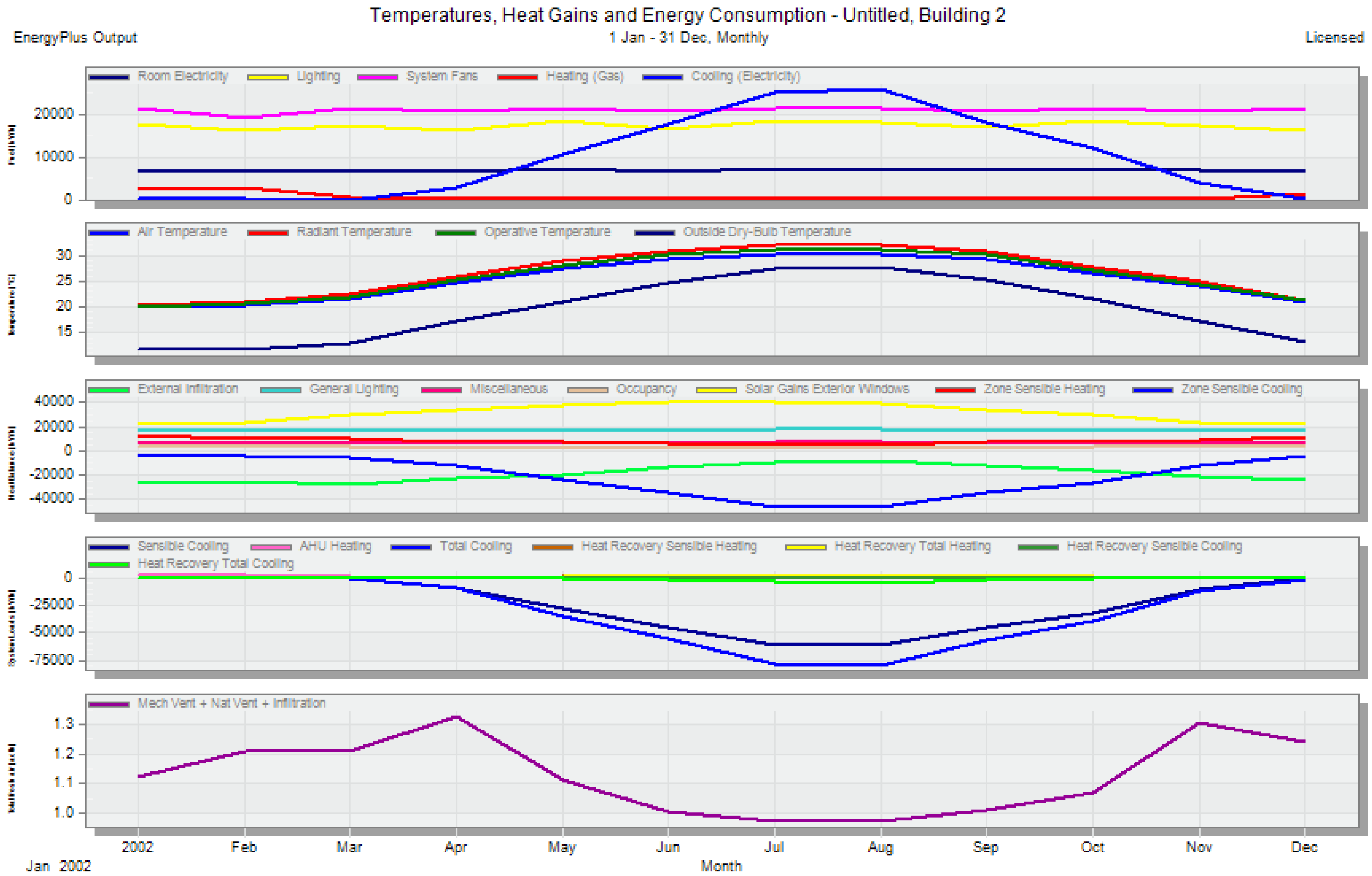


Vertical Shading and PV on Northwest Facade

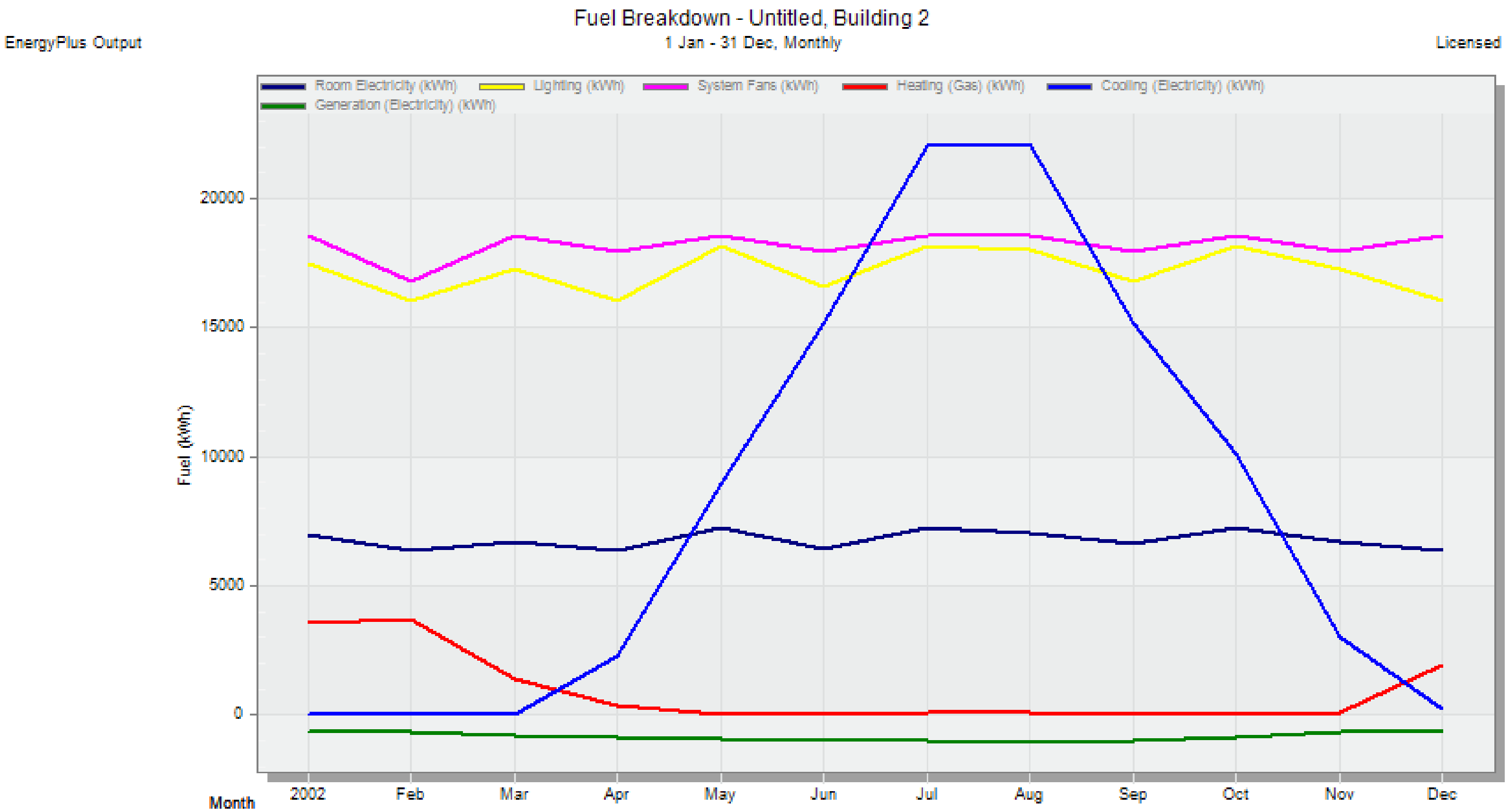


Horizontal Shading and PV on Northwest Façade

Appendix G: Colored Building Simulation Before Integrated PV from (January -December)

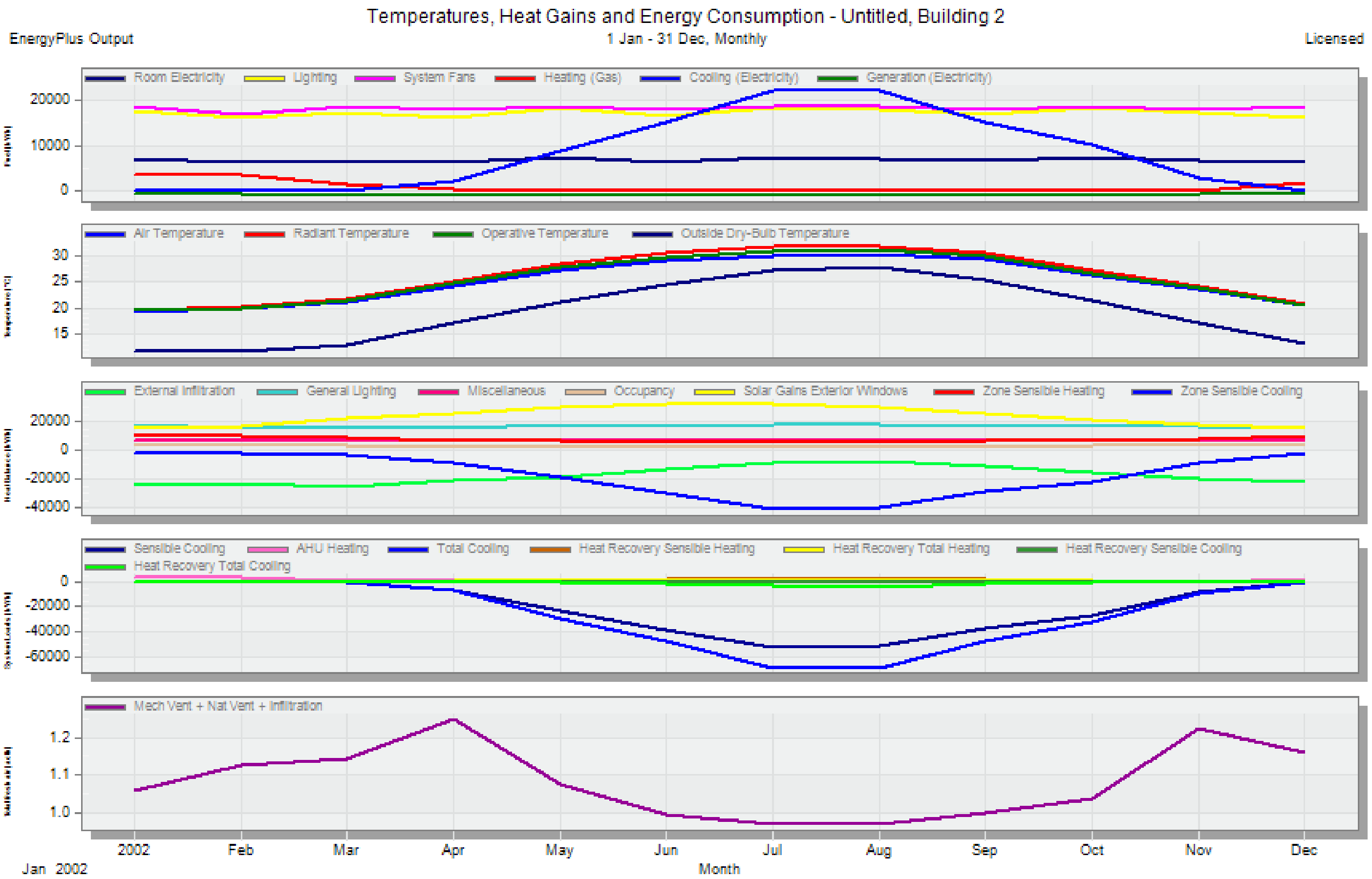


Temperature, Heat, Gains and Energy Consumption

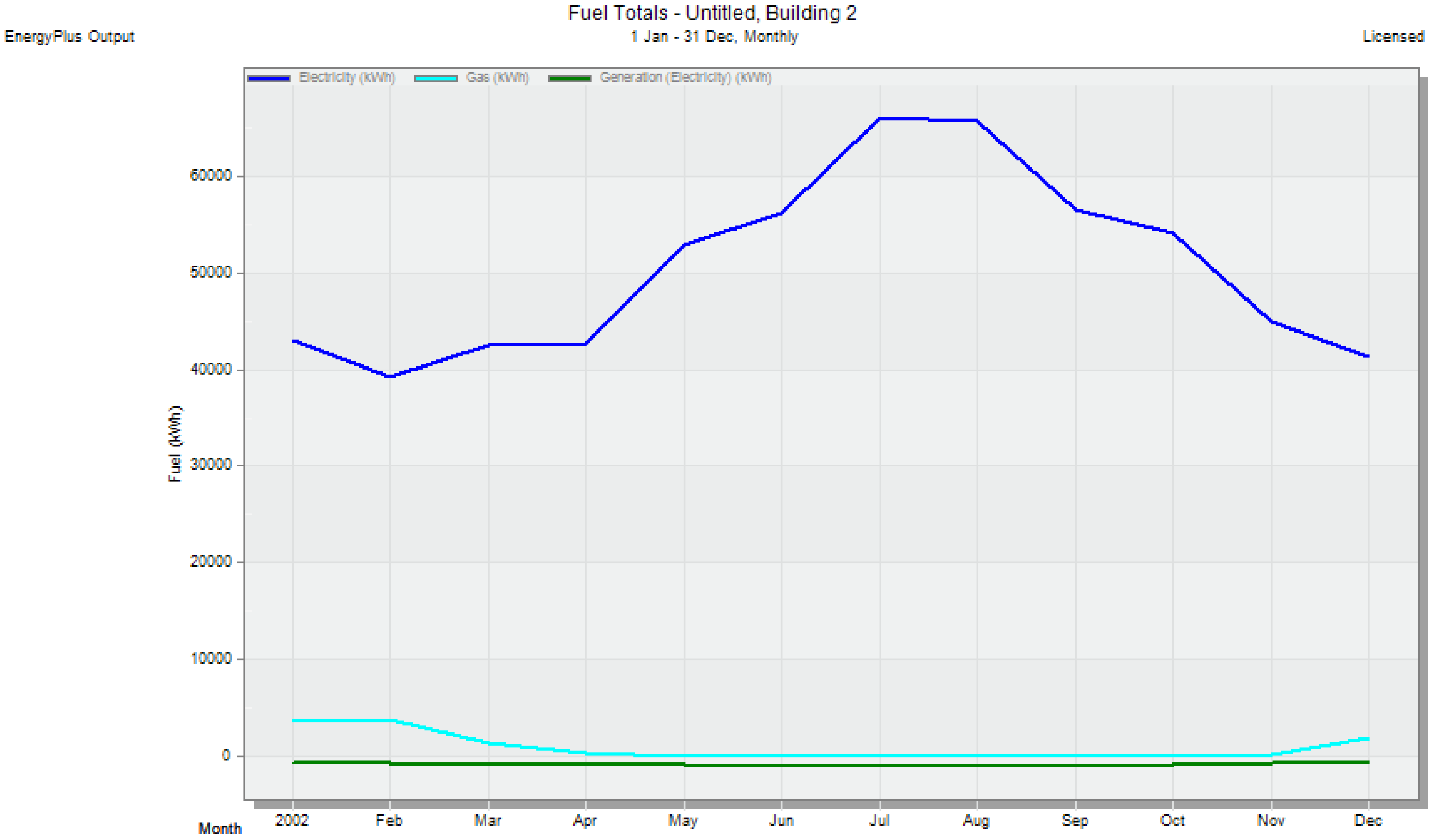


Room Electricity (kWh)	6947.15	6345.09	6727.23	6345.09	7248.19	6426.20	7248.19	7009.54	6664.84	7248.19	6708.51	6363.81
Lighting (kWh)	17469.27	16071.73	17294.58	16071.73	18168.04	16595.81	18168.04	17993.35	16770.50	18168.04	17294.58	16071.73
System Fans (kWh)	18576.85	16779.09	18576.85	17977.60	18576.85	17977.60	18576.85	18576.85	17977.60	18576.85	17977.60	18576.85
Heating (Gas) (kWh)	3599.46	3732.58	1367.11	369.68	0.64	44.26	60.96	76.13	37.99	5.08	108.18	1924.38
Cooling (Electricity) (kWh)	0.00	0.59	0.00	2278.16	8941.27	15122.84	22039.92	22142.38	15126.34	10140.67	2998.47	243.89
;eneration (Electricity) (kWh)	-631.46	-668.32	-799.85	-882.15	-932.33	-991.68	-1011.69	-1035.82	-985.21	-846.58	-673.60	-628.71

Fuel Breakdown



Temperature, Heat, Gains and Energy Consumption



	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity (kWh)	42993.27	39196.49	42598.66	42672.57	52934.35	56122.44	66033.00	65722.12	56539.27	54133.75	44979.15	41256.27
Gas (kWh)	3599.46	3732.58	1367.11	369.68	0.64	44.26	60.96	76.13	37.99	5.08	108.18	1924.38
;eneration (Electricity) (kWh)	-631.46	-668.32	-799.85	-882.15	-932.33	-991.68	-1011.69	-1035.82	-985.21	-846.58	-673.60	-628.71

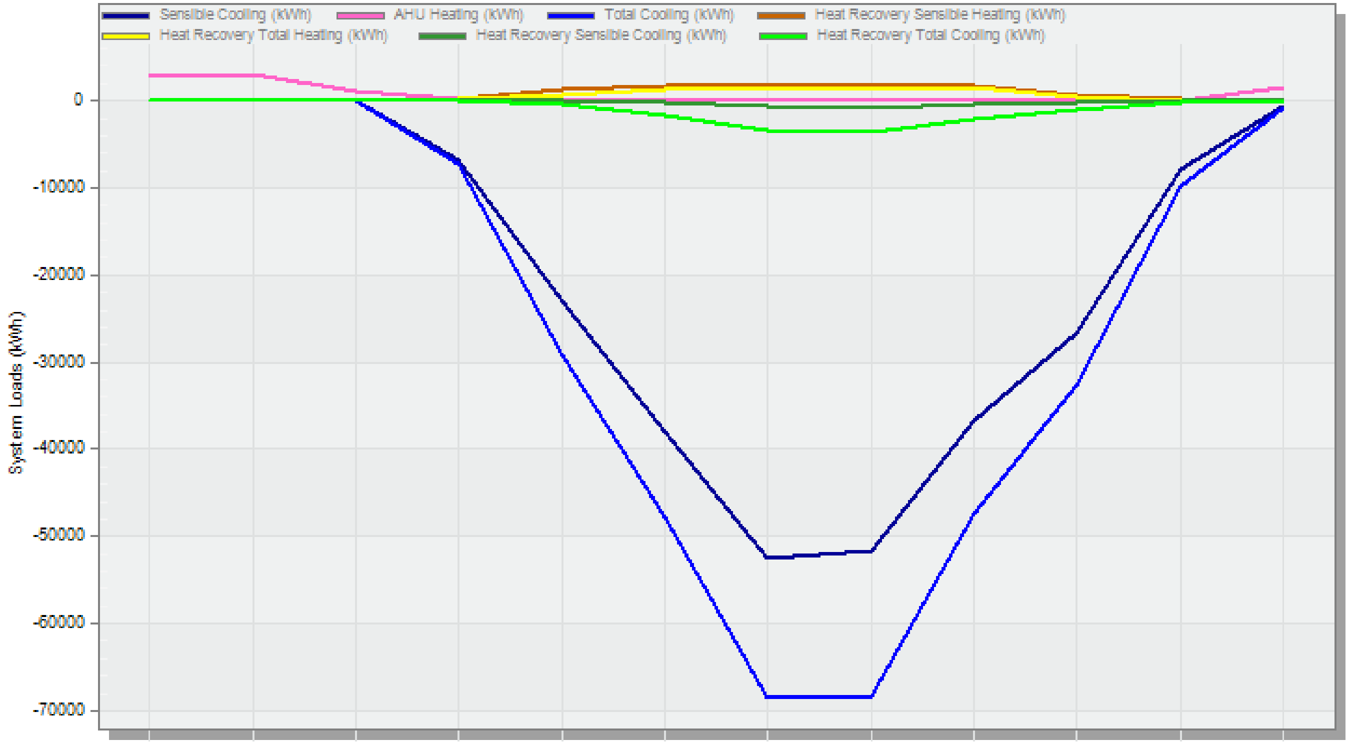
Fuel Totals

EnergyPlus Output

- Untitled, Building 2

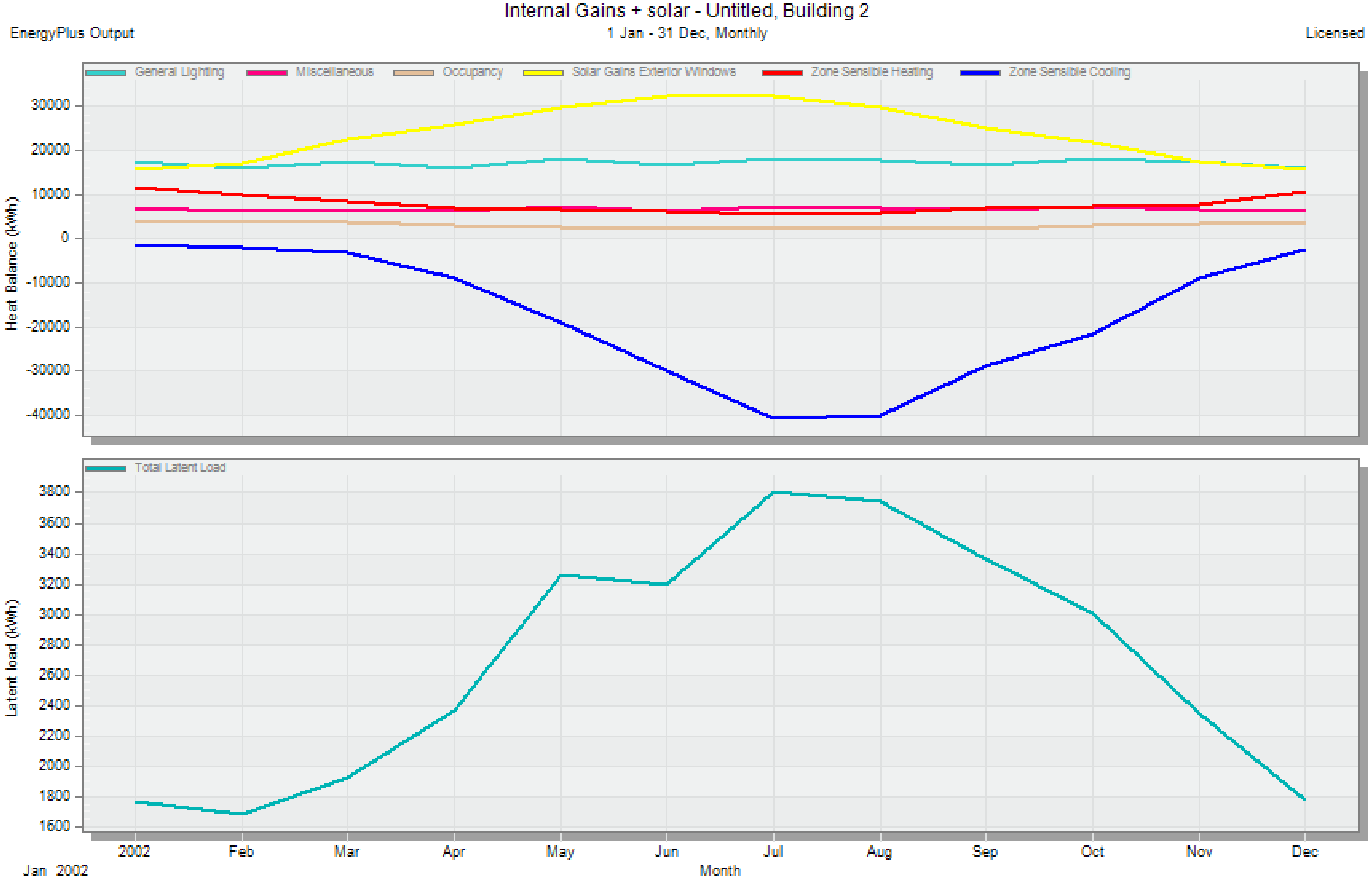
1 Jan - 31 Dec, Monthly

Licensed



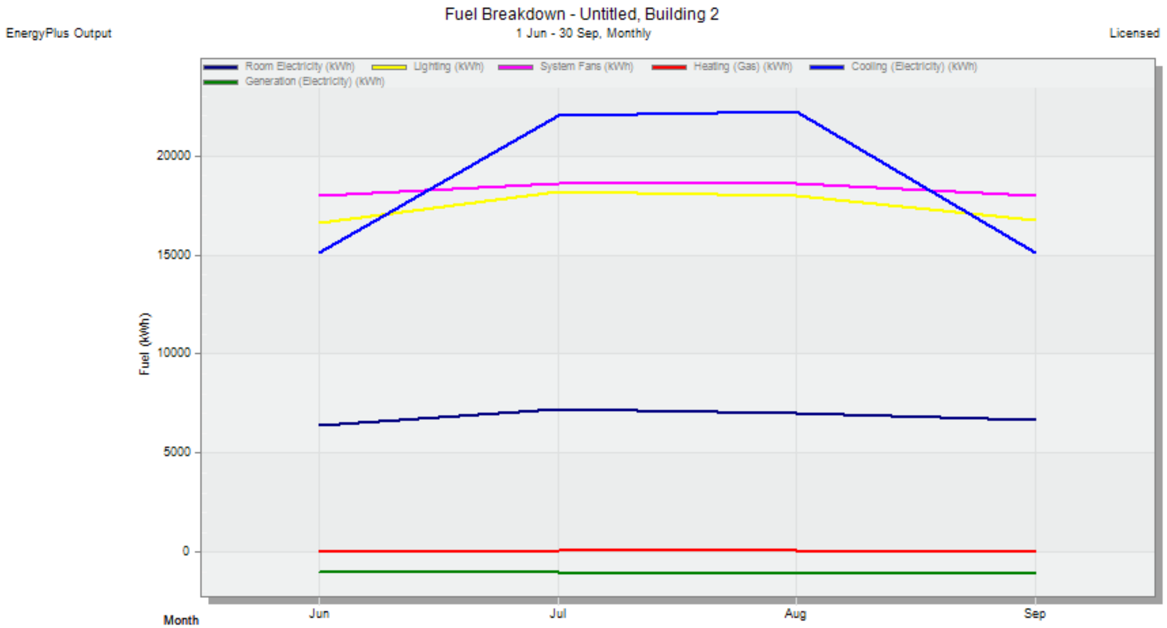
Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sensible Cooling (kWh)	0.00	-1.85	0.00	-6807.99	-23130.06	-38072.86	-52554.91	-51752.52	-36754.13	-26731.82	-7802.29	-551.15
AHU Heating (kWh)	2879.57	2986.07	1093.69	295.74	0.51	35.41	48.77	60.90	30.39	4.07	86.54	1539.50
Total Cooling (kWh)	0.00	-1.98	0.00	-7185.54	-29251.09	-47883.89	-68477.23	-68270.39	-47423.23	-32571.70	-9844.42	-812.44
Heat Recovery Sensible Heating (kWh)	0.00	0.00	0.00	352.79	1243.65	1772.24	1784.13	1721.60	1680.10	708.89	189.02	14.27
Heat Recovery Total Heating (kWh)	0.00	0.00	0.00	350.48	741.33	1284.93	1477.60	1374.59	1448.97	522.00	114.28	8.16
Heat Recovery Sensible Cooling (kWh)	0.00	0.00	0.00	-21.22	-20.24	-235.52	-624.86	-743.08	-308.58	-210.09	-34.39	0.00
Heat Recovery Total Cooling (kWh)	0.00	0.00	0.00	-24.60	-479.56	-1586.22	-3405.65	-3617.11	-2059.07	-962.81	-274.06	-0.06

System Load



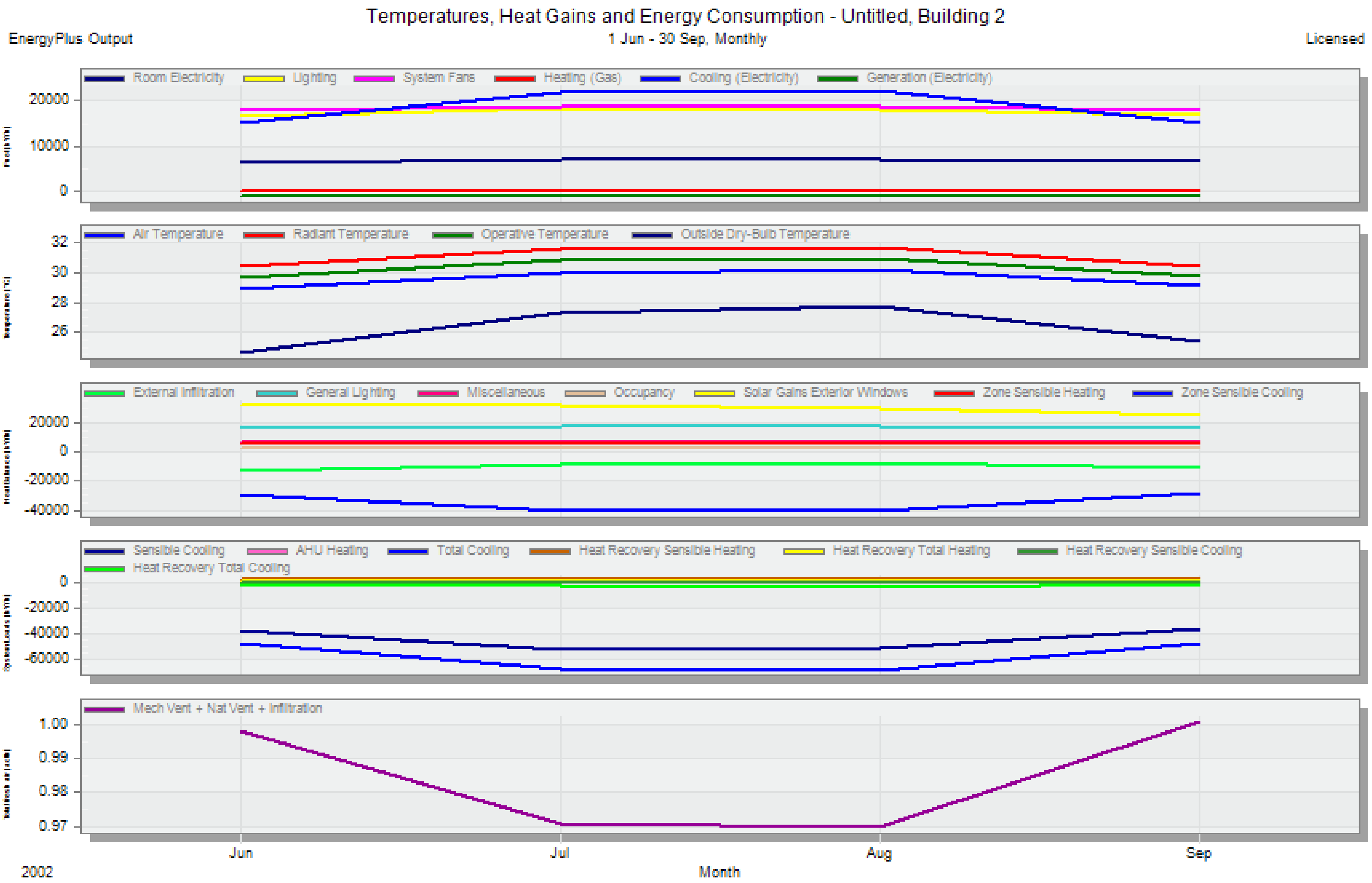
Internal Gains and Solar

Appendix H: Colored Building Simulation After Integrated PV Panels in Horizontal Shading Southwest Facade from (June -September)

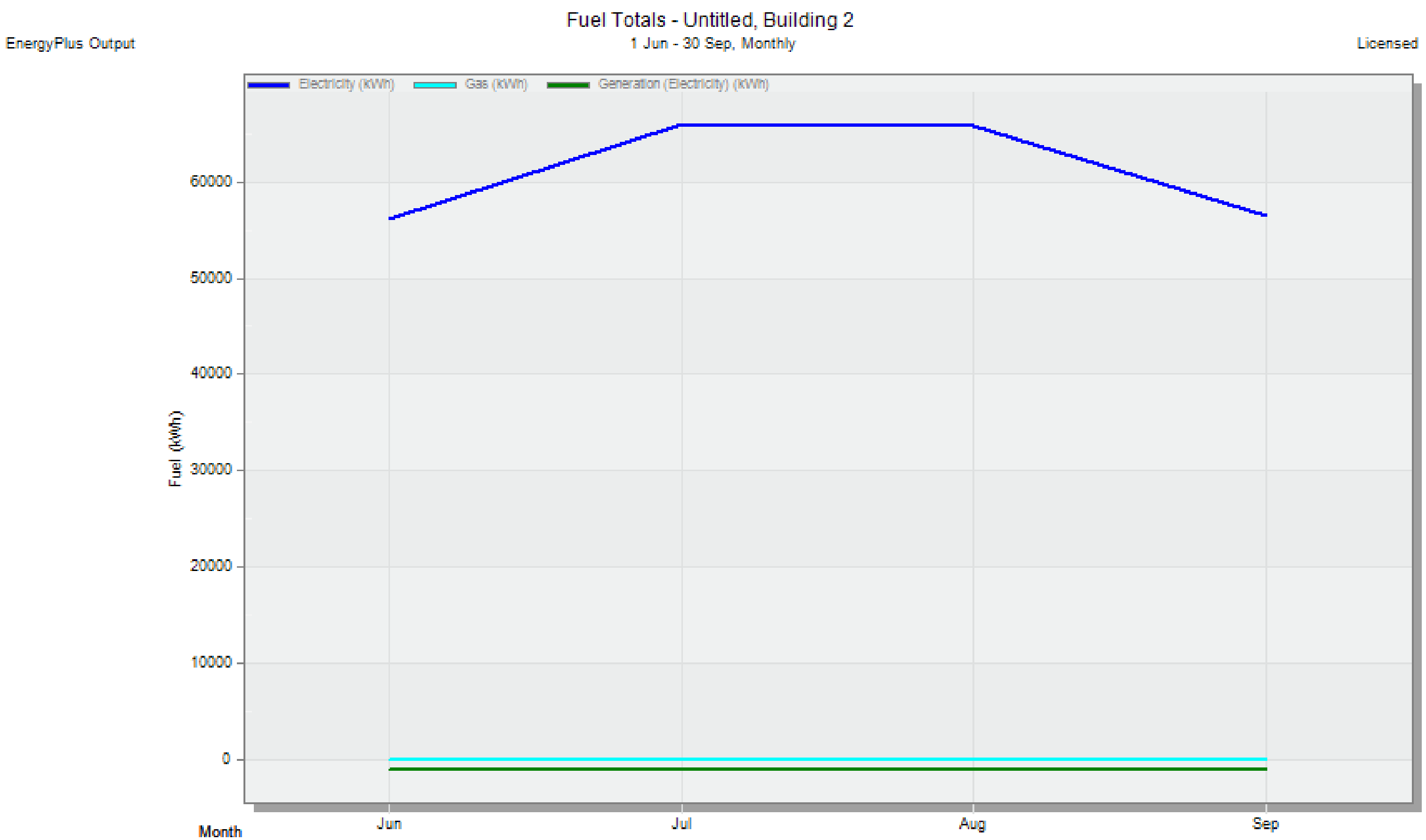


Month	Jun	Jul	Aug	Sep
Room Electricity (kWh)	6426.20	7248.19	7009.54	6664.84
Lighting (kWh)	16595.81	18168.04	17993.35	16770.50
System Fans (kWh)	17977.60	18576.85	18576.85	17977.60
Heating (Gas) (kWh)	44.47	60.21	74.02	40.22
Cooling (Electricity) (kWh)	15134.90	22002.54	22266.71	15104.90
Generation (Electricity) (kWh)	-989.18	-1009.08	-1041.46	-976.90

Fuel Breakdown



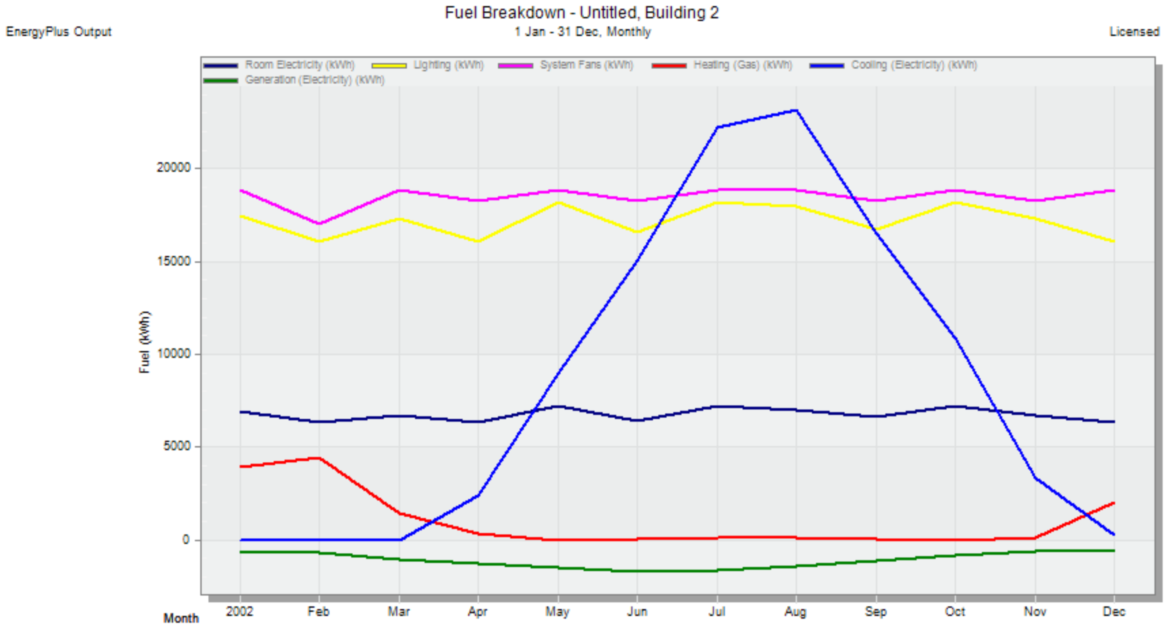
Temperature, Heat, Gains and Energy Consumption



Electricity (kWh)	56134.50	65995.61	65846.46	56517.83
Gas (kWh)	44.47	60.21	74.02	40.22
;eneration (Electricity) (kWh)	-989.18	-1009.08	-1041.46	-976.90

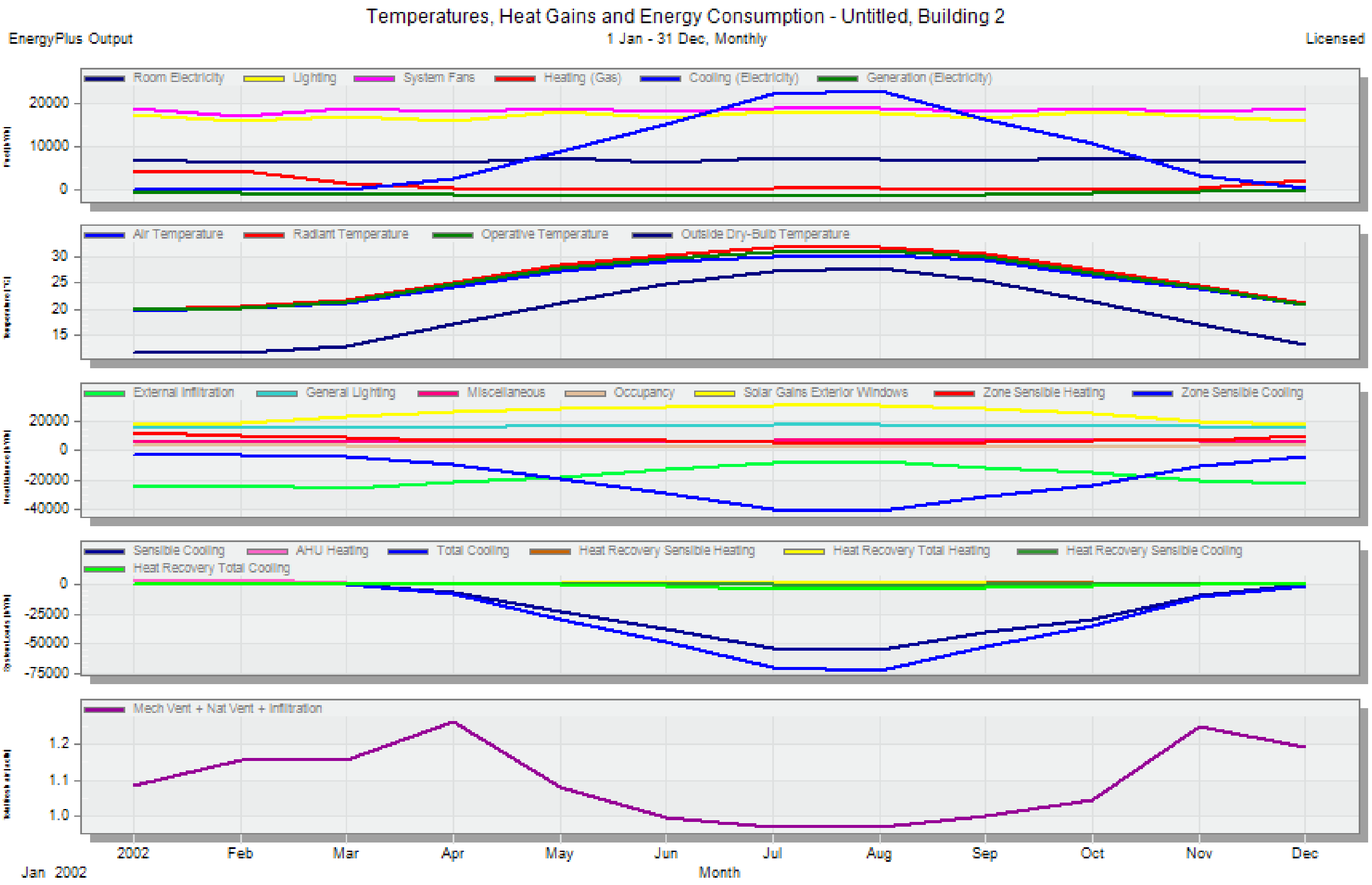
Fuel Totals

Appendix I: Colored Building Simulation After Integrated PV Panels in Horizontal Shading Northwest Facade from (January -December)

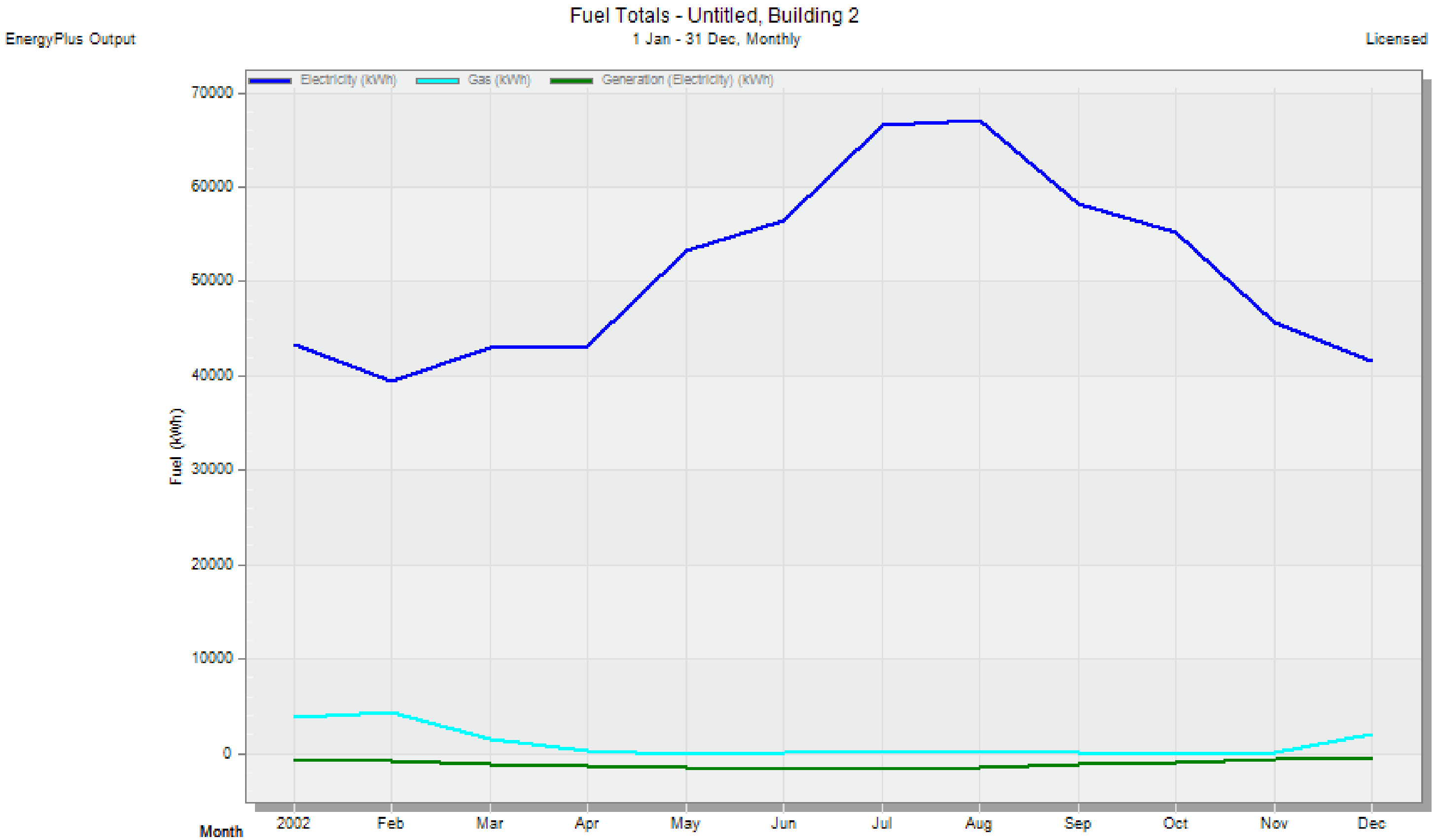


Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Room Electricity (kWh)	6947.15	6345.09	6727.23	6345.09	7248.19	6426.20	7248.19	7009.54	6664.84	7248.19	6708.51	6363.81
Lighting (kWh)	17469.27	16071.73	17294.58	16071.73	18168.04	16595.81	18168.04	17993.35	16770.50	18168.04	17294.58	16071.73
System Fans (kWh)	18891.69	17063.46	18891.69	18282.28	18891.69	18282.28	18891.69	18891.69	18282.28	18891.69	18282.28	18891.69
Heating (Gas) (kWh)	3892.48	4431.37	1443.51	341.96	0.00	50.12	114.25	151.56	56.98	6.16	82.17	1992.53
Cooling (Electricity) (kWh)	0.00	0.54	0.00	2388.49	8974.91	15087.37	22231.19	23219.43	16525.92	10891.62	3338.69	273.13
Generation (Electricity) (kWh)	-602.51	-718.87	-1050.09	-1256.72	-1520.26	-1676.58	-1628.26	-1431.74	-1094.56	-864.11	-644.44	-567.13

Fuel Breakdown

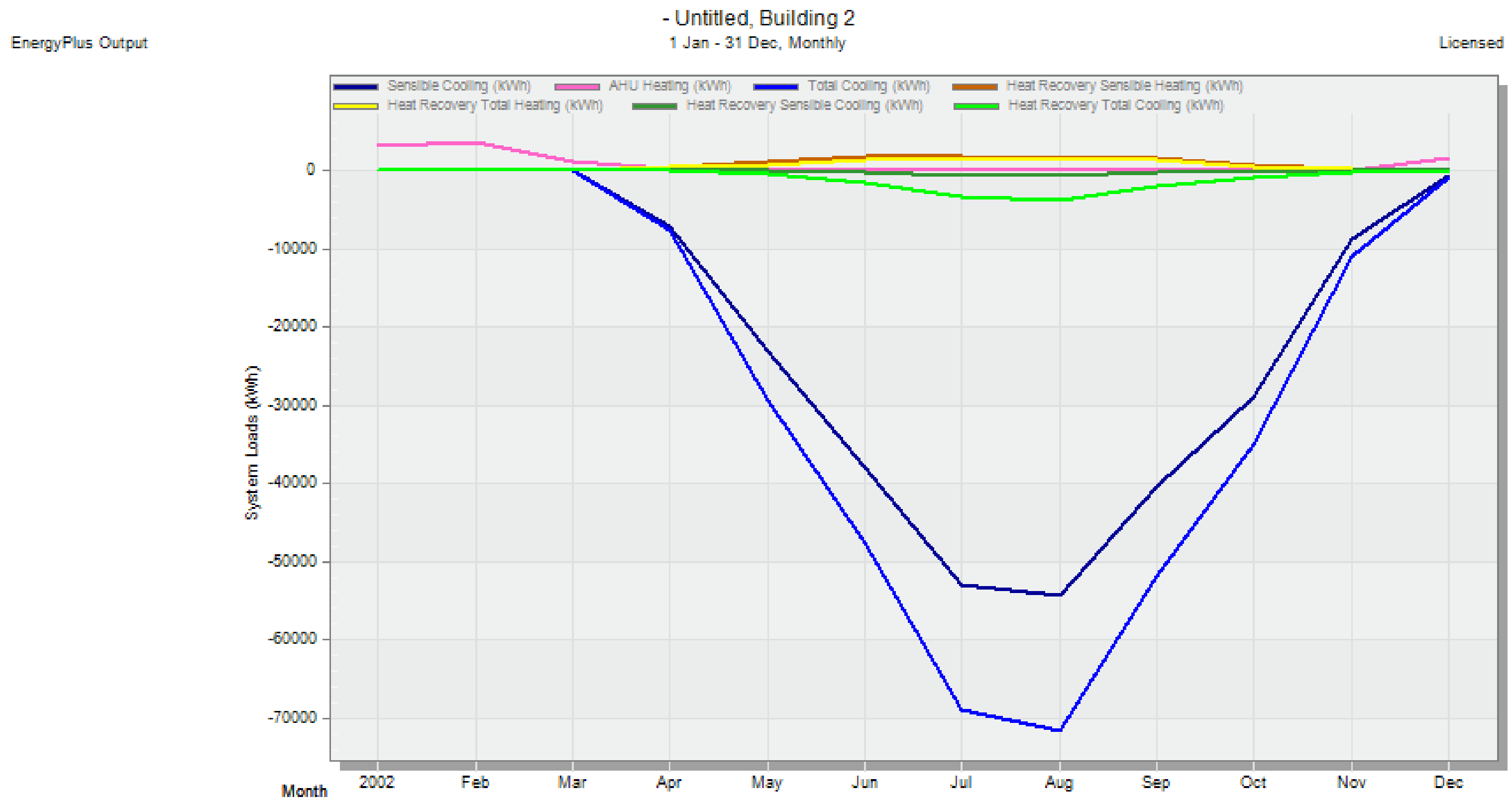


Temperature, Heat, Gains and Energy Consumption



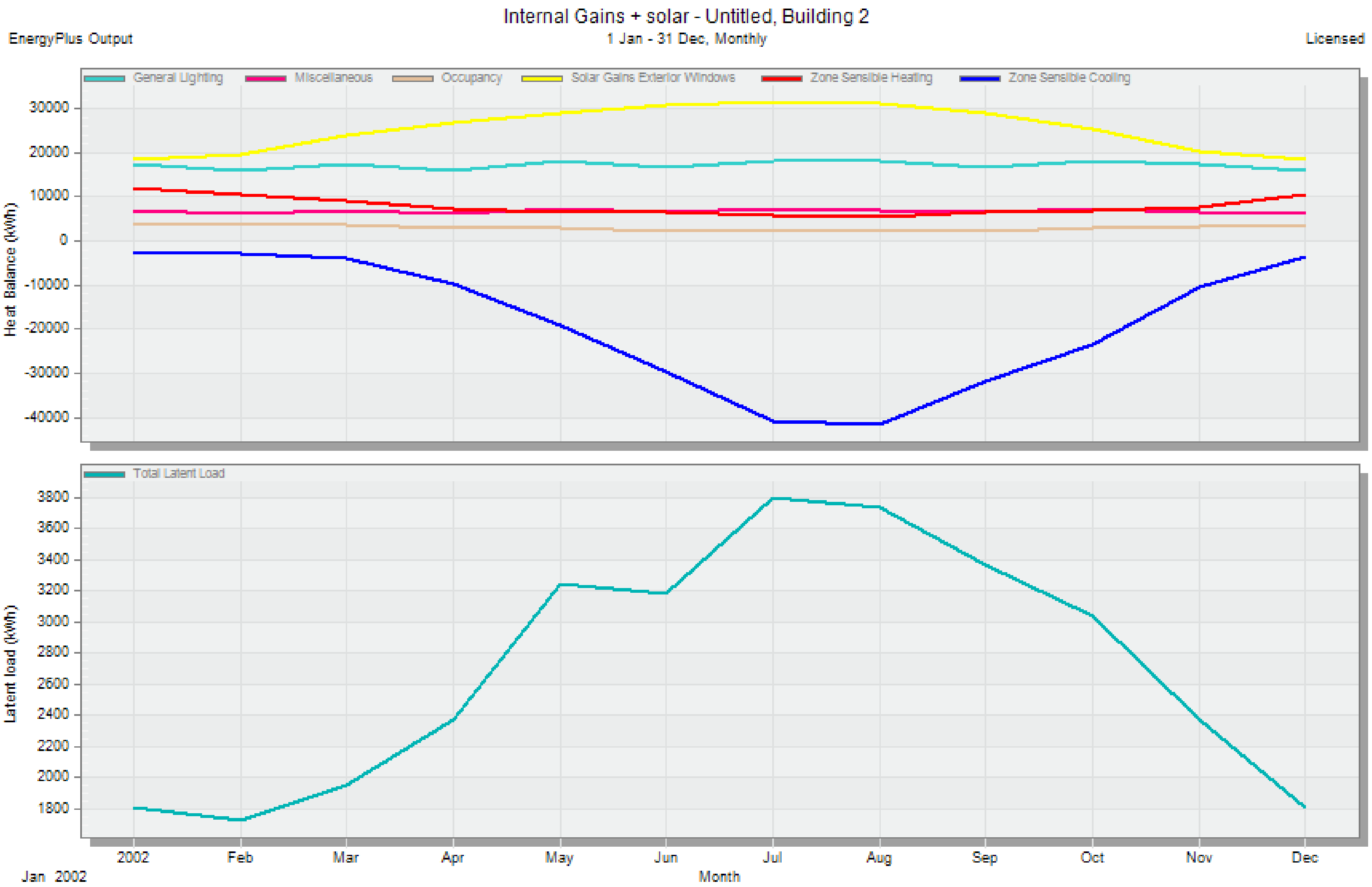
Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity (kWh)	43308.11	39480.81	42913.49	43087.58	53282.82	56391.65	66539.11	67114.01	58243.54	55199.53	45624.06	41600.36
Gas (kWh)	3892.48	4431.37	1443.51	341.96	0.00	50.12	114.25	151.56	56.98	6.16	82.17	1992.53
Generation (Electricity) (kWh)	-602.51	-718.87	-1050.09	-1256.72	-1520.26	-1676.58	-1628.26	-1431.74	-1094.56	-864.11	-644.44	-567.13

Fuel Totals



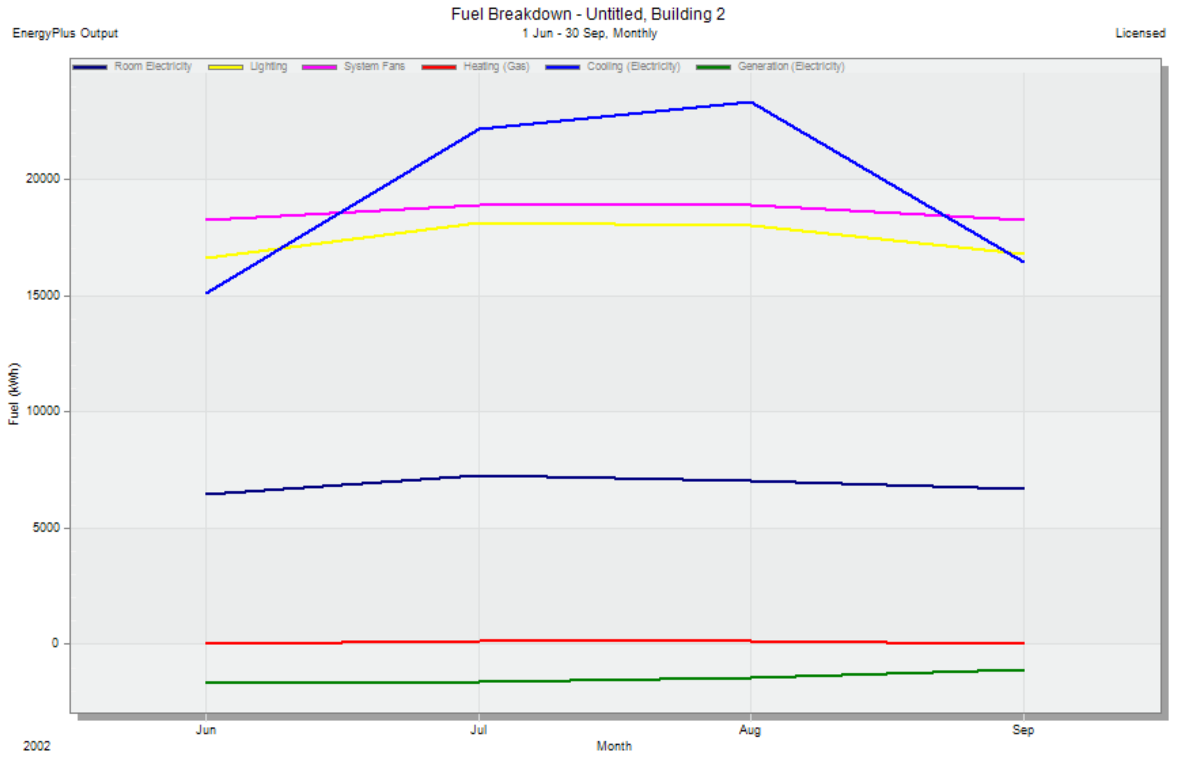
Sensible Cooling (kWh)	0.00	-1.69	0.00	-7134.06	-23217.50	-37923.53	-52979.30	-54353.07	-40512.46	-29027.72	-8828.73	-613.11
AHU Heating (kWh)	3113.98	3545.10	1154.81	273.56	0.00	40.10	91.40	121.25	45.58	4.92	65.74	1594.03
Total Cooling (kWh)	0.00	-1.80	0.00	-7548.98	-29335.05	-47701.18	-68989.15	-71584.84	-51855.55	-35035.75	-10986.71	-909.05
Heat Recovery Sensible Heating (kWh)	0.00	0.00	0.00	355.96	1234.79	1755.10	1758.02	1663.71	1682.27	748.57	205.20	17.81
Heat Recovery Total Heating (kWh)	0.00	0.00	0.00	349.97	729.20	1276.19	1434.56	1266.99	1369.82	519.70	123.61	11.51
Heat Recovery Sensible Cooling (kWh)	0.00	0.00	0.00	-21.83	-20.71	-243.28	-628.84	-746.34	-305.61	-191.57	-32.97	0.00
Heat Recovery Total Cooling (kWh)	0.00	0.00	0.00	-26.76	-486.61	-1610.50	-3450.39	-3764.92	-2129.31	-953.08	-282.63	-0.01

System Load

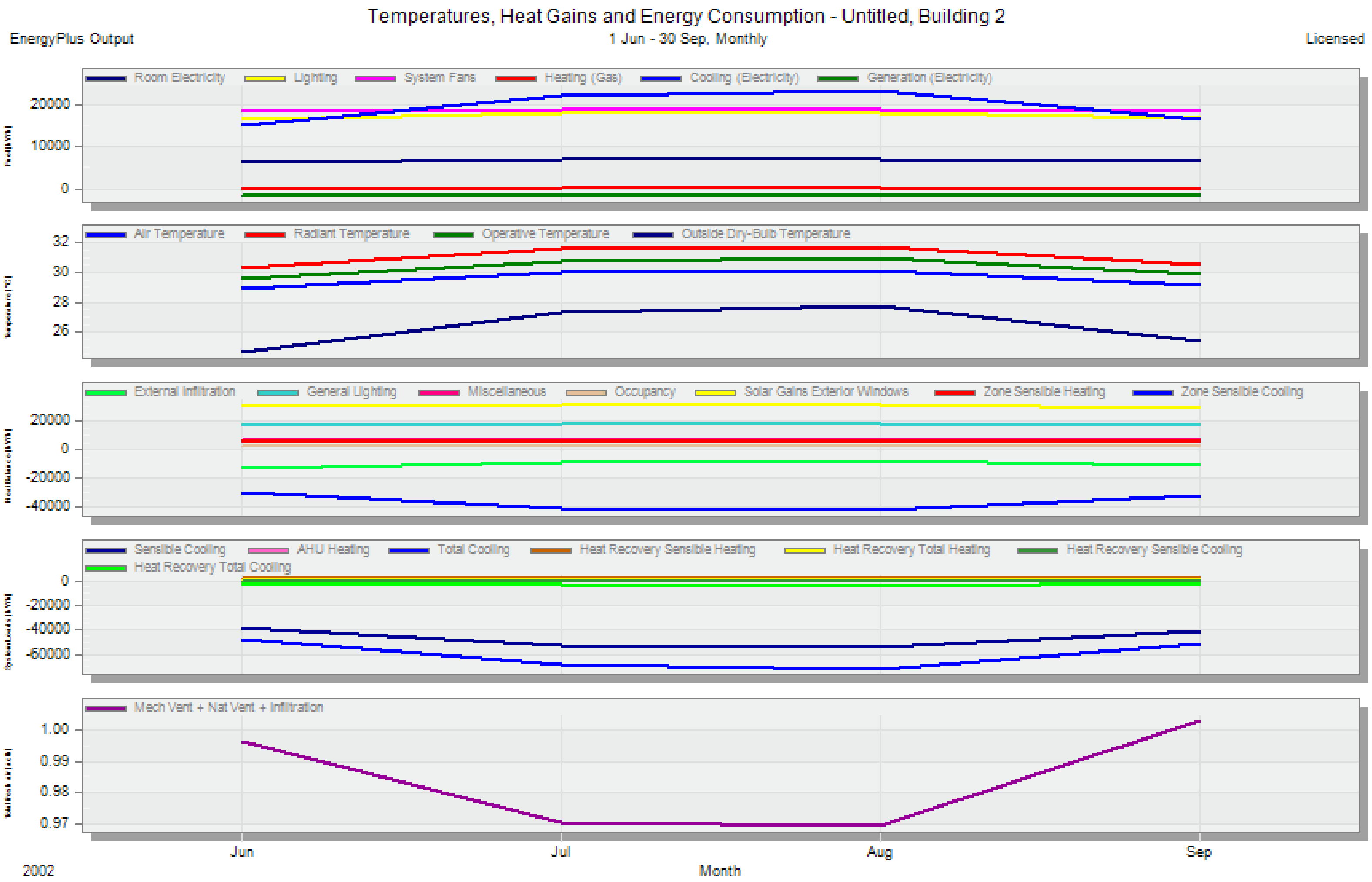


Internal Gains

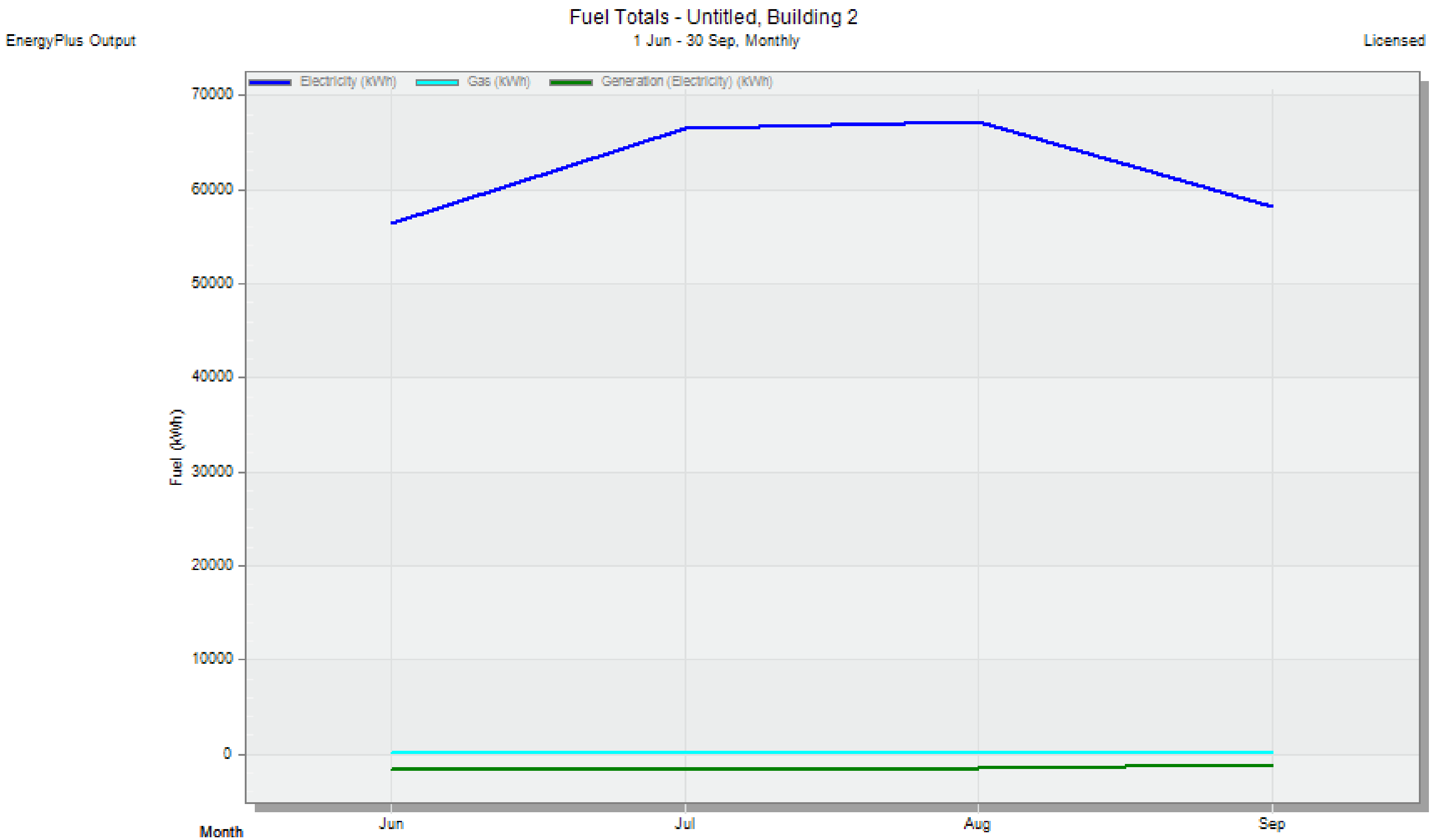
Appendix J: Colored Building Simulation After Integrated PV Panels in Horizontal Shading Northwest Facade from (June -September)



Fuel Breakdown



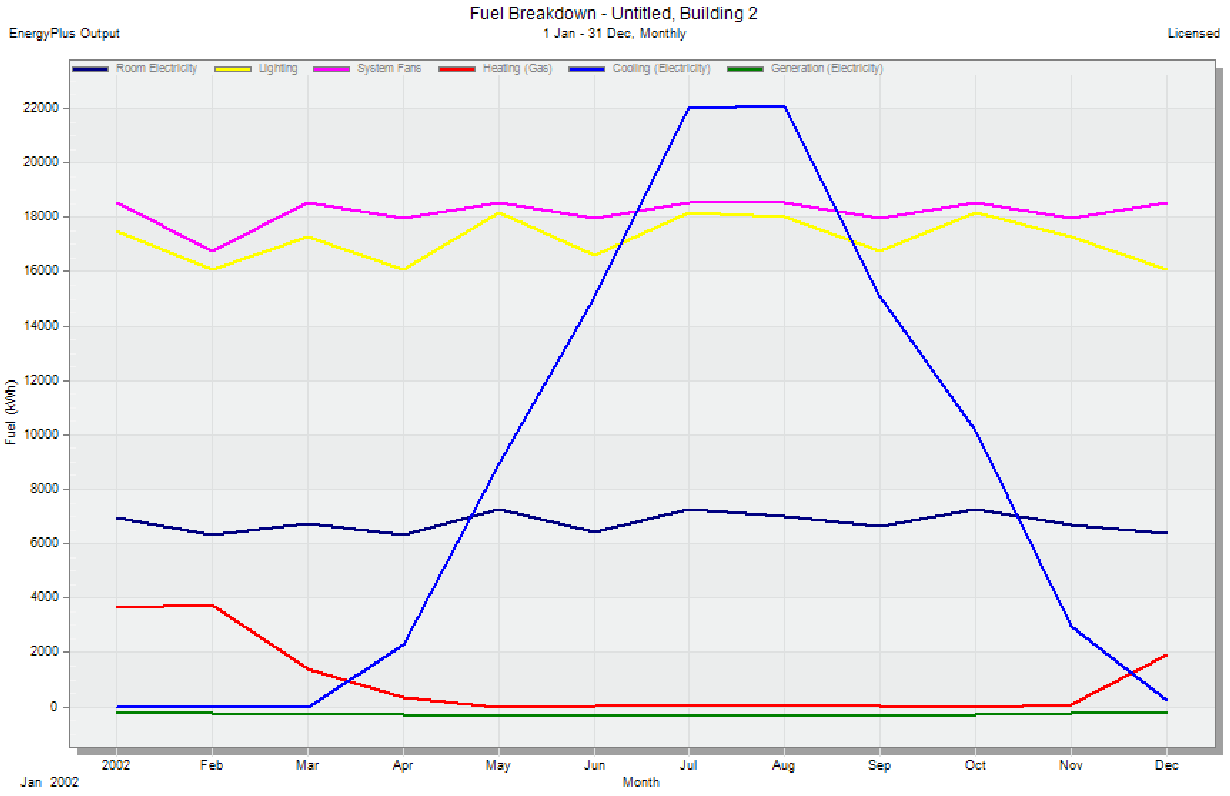
Temperature, Heat, Gains and Energy Consumption



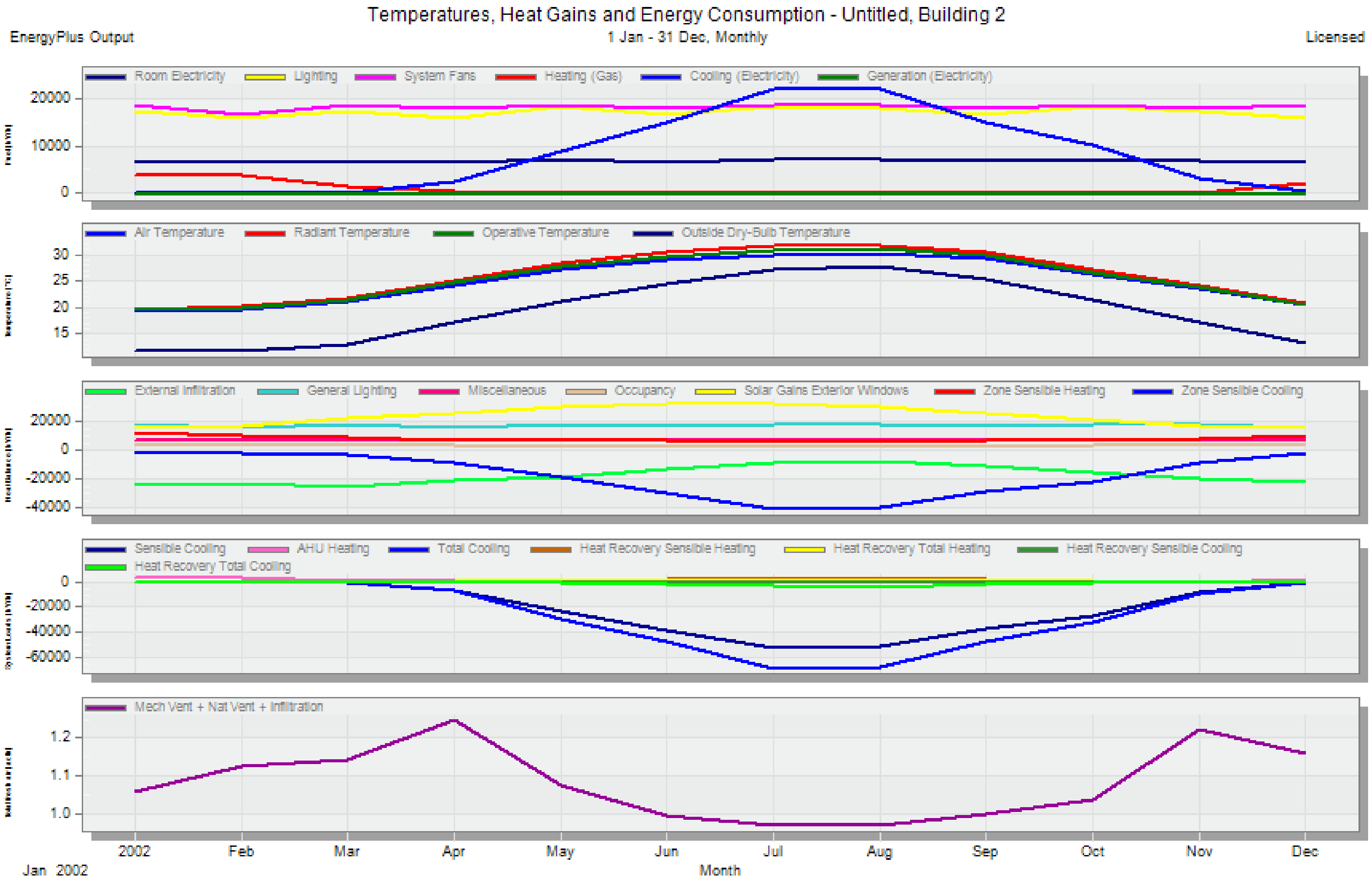
	Jun	Jul	Aug	Sep
Electricity (kWh)	56396.77	66502.13	67239.88	58183.97
Gas (kWh)	50.02	113.27	149.02	51.95
Generation (Electricity) (kWh)	-1676.99	-1632.67	-1427.06	-1097.97

Fuel Totals

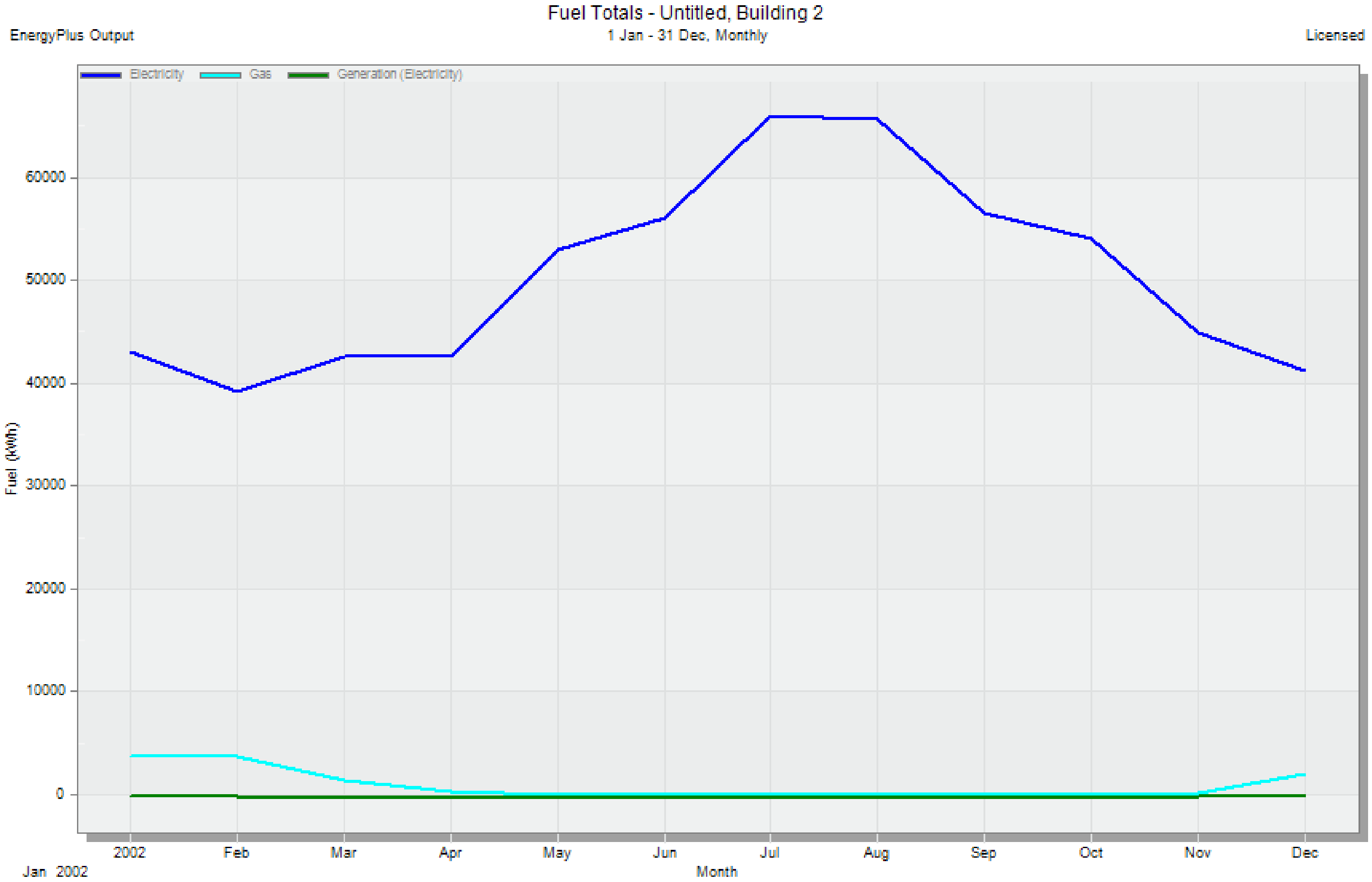
Appendix K: Colored Building Simulation After Integrated PV Panels in Vertical Shading Southwest Facade from (January -December)



Fuel Breakdown

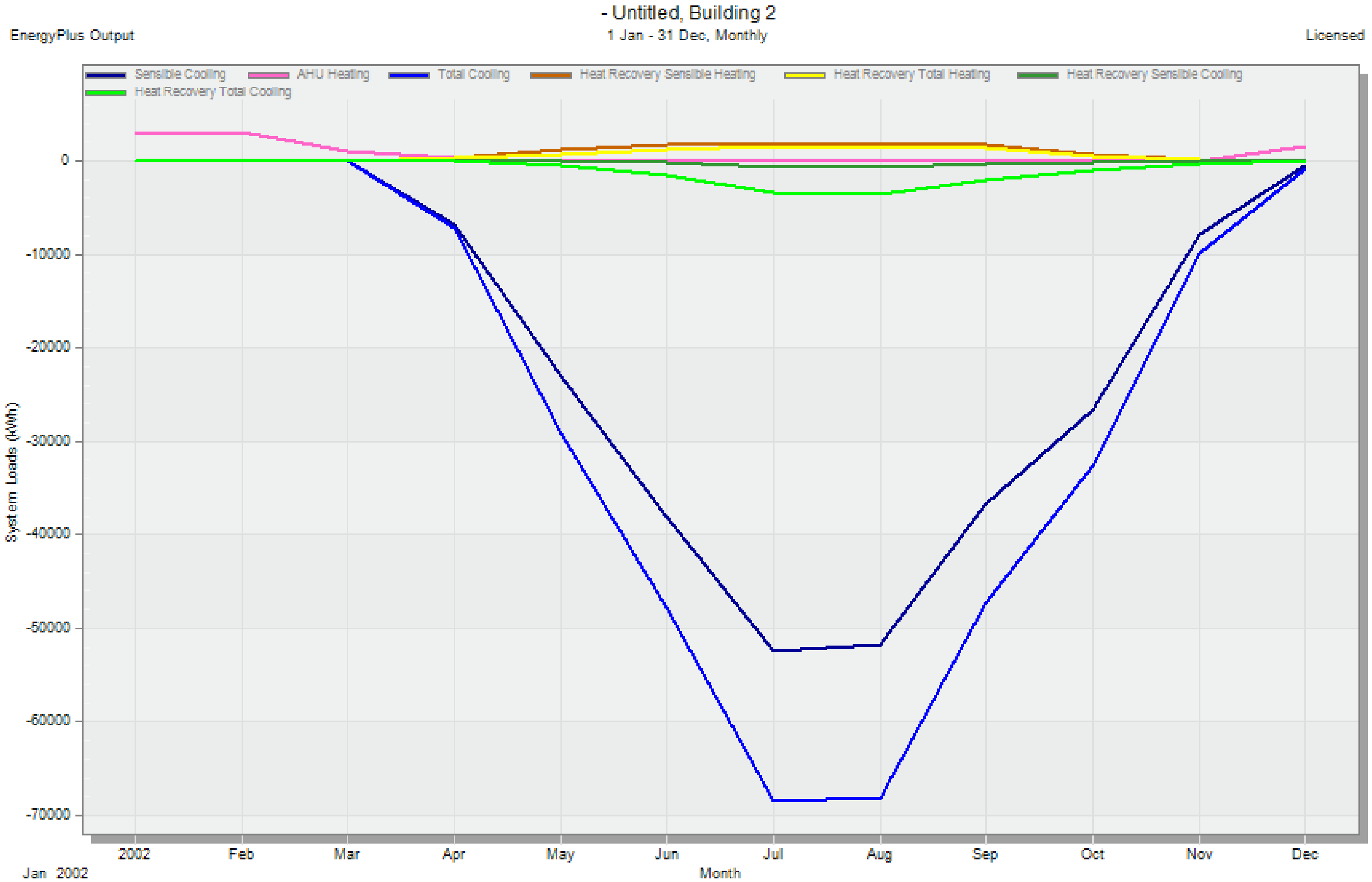


Temperature, Heat, Gains and Energy Consumption

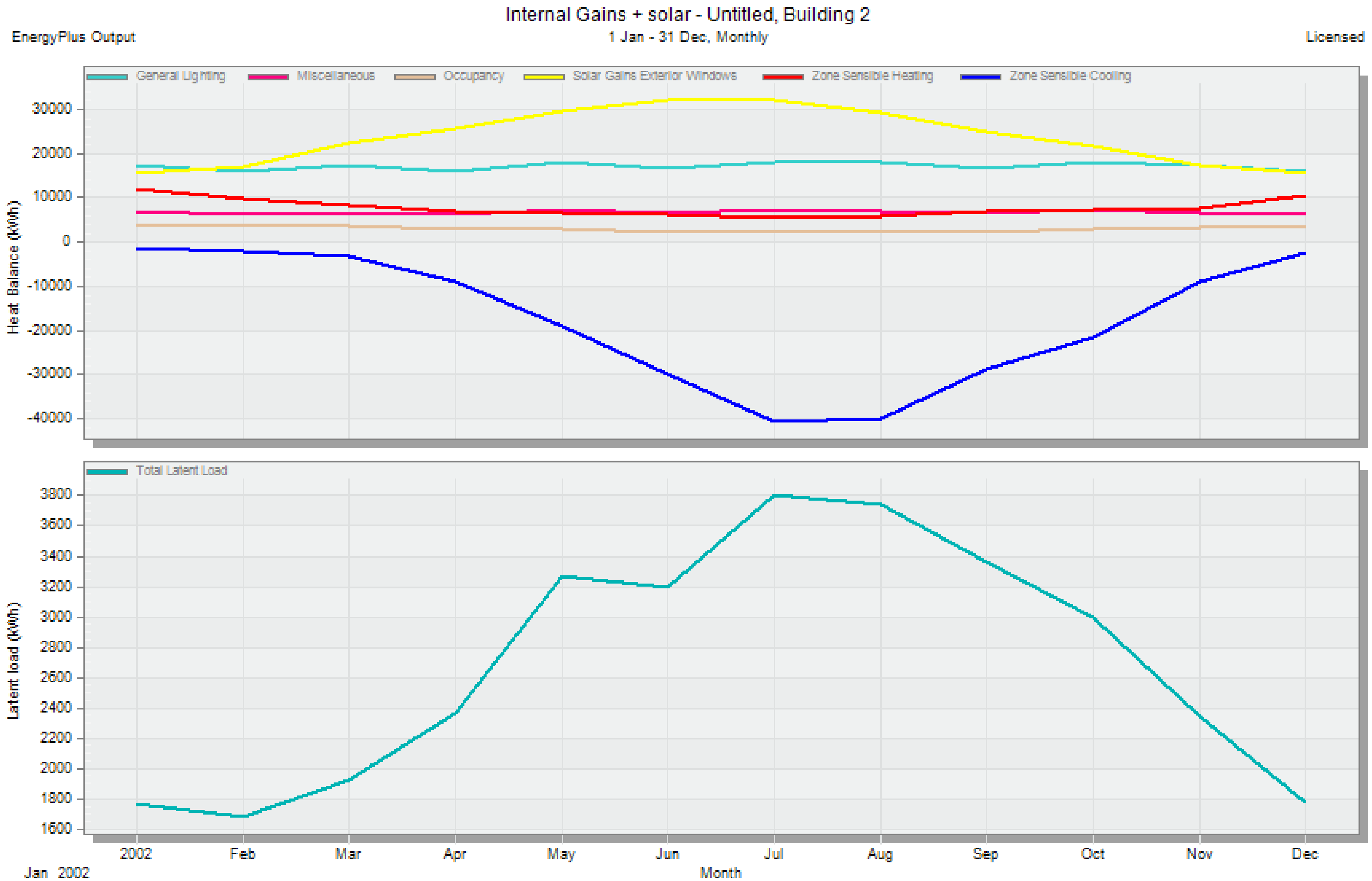


Fuel Totals - Untitled, Building 2
EnergyPlus Output
1 Jan - 31 Dec, Monthly
Licensed
Electricity
Gas
Generation (Electricity)
Fuel (kWh)
60000
50000
40000
30000
20000
10000
0
2002
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan 2002
Month

Fuel Totals

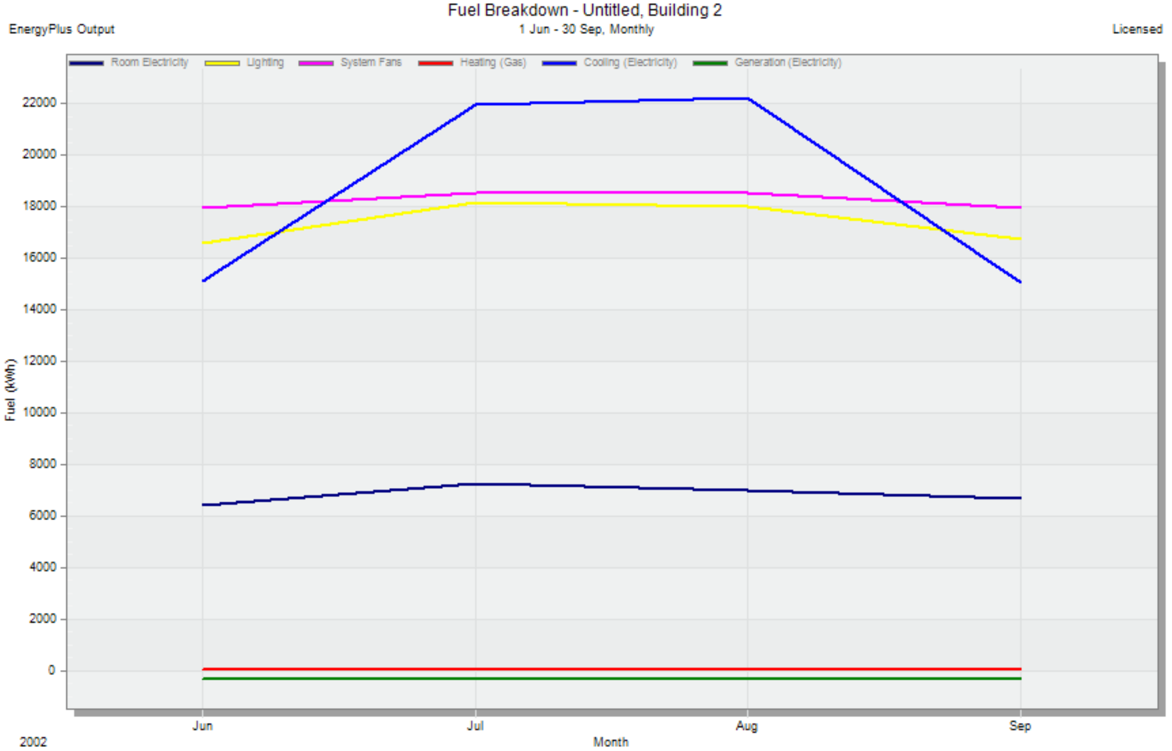


System Load

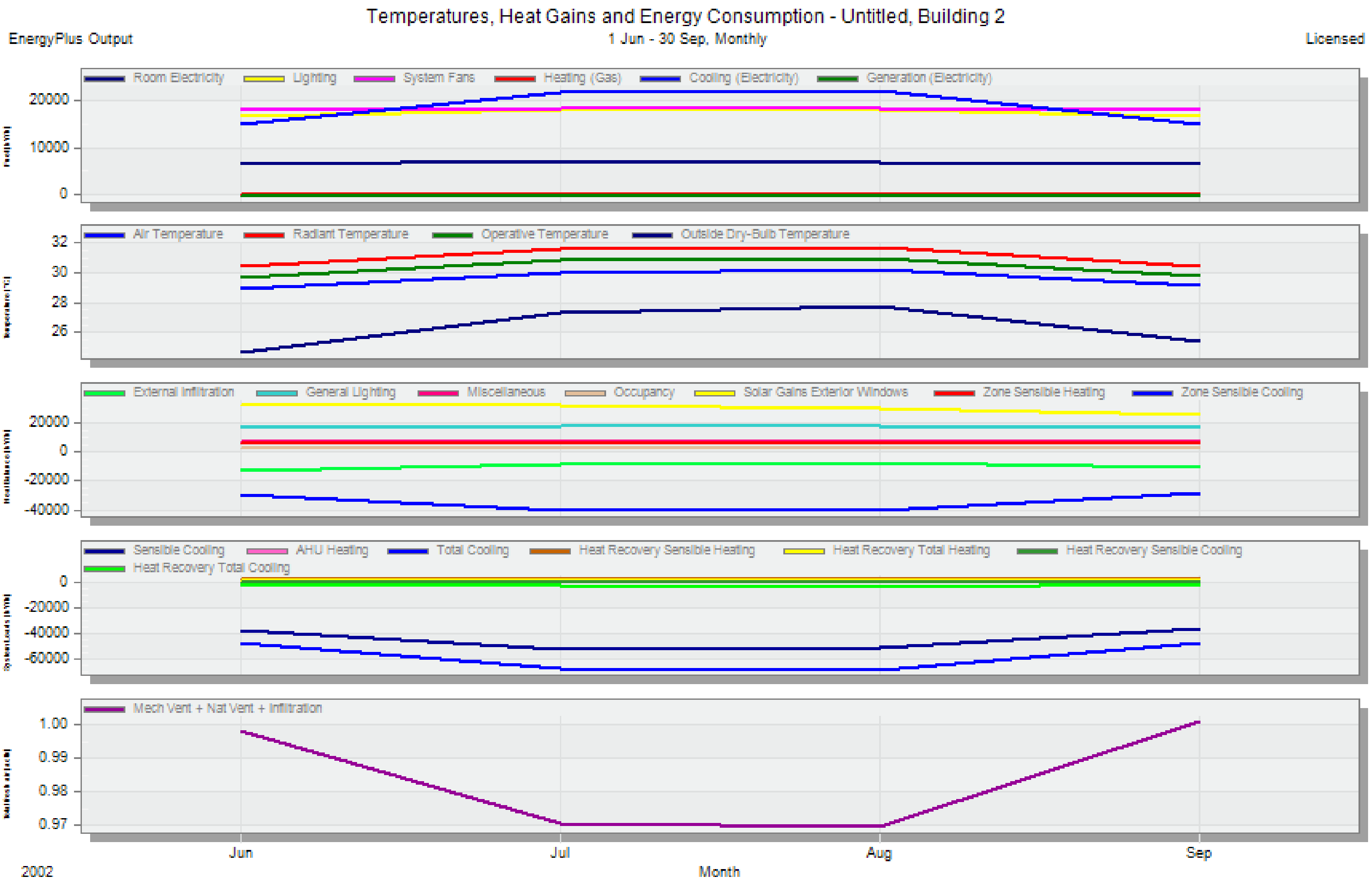


Internal Gains

Appendix L: Colored Building Simulation After Integrated PV Panels in Vertical Shading Southwest Facade from (June -September)

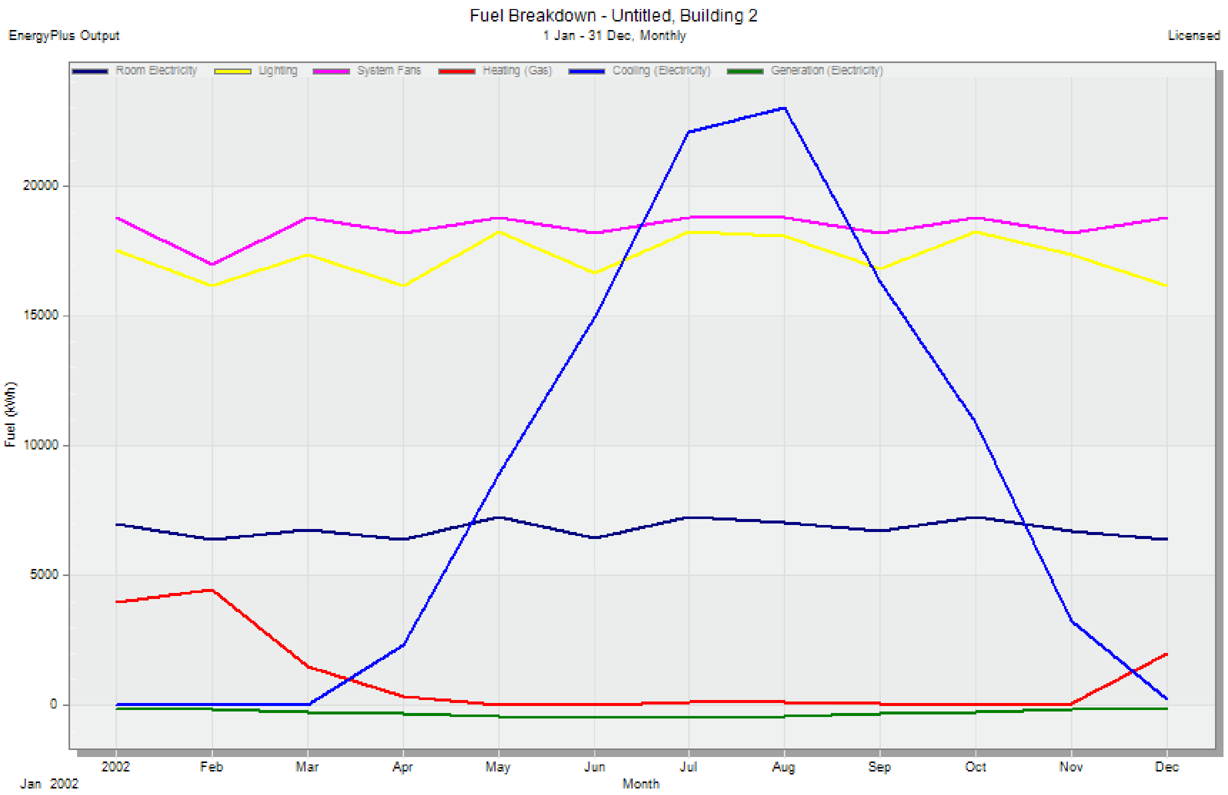


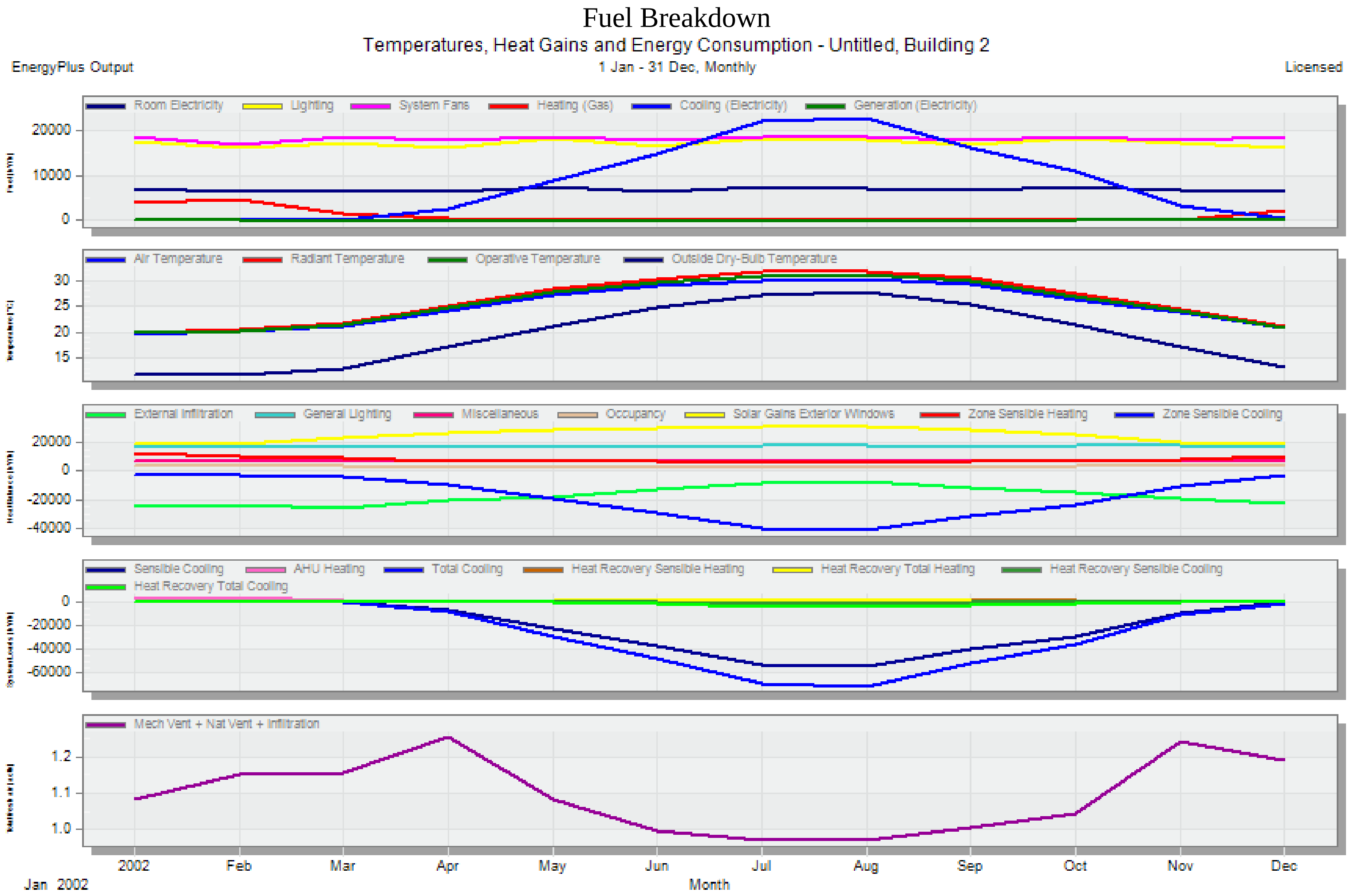
Fuel Breakdown



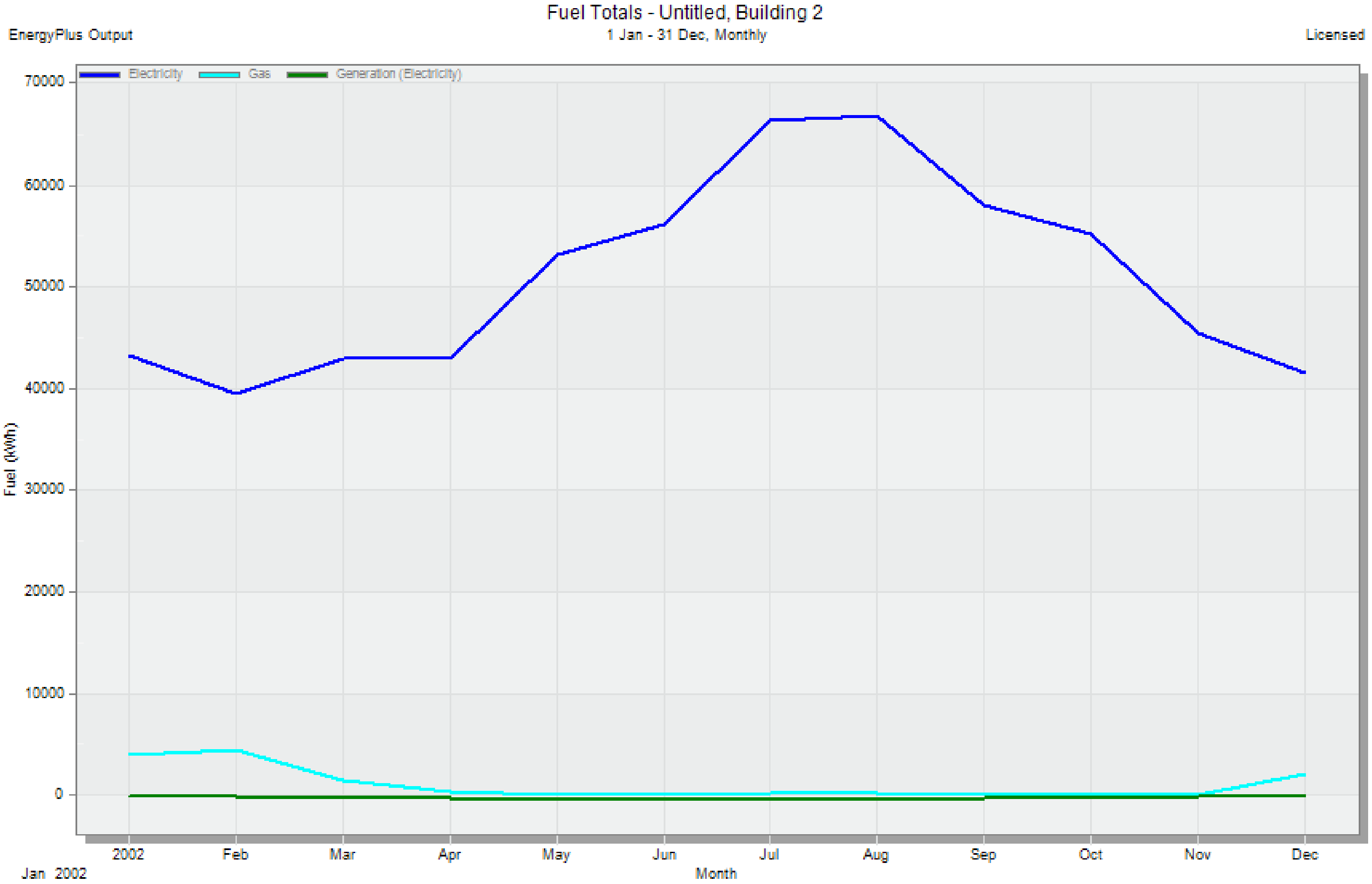
Temperature, Heat, Gains and Energy Consumption

Appendix M: Colored Building Simulation After Integrated PV Panels in Vertical Shading Northwest Facade from (January -December)





Temperature, Heat, Gains and Energy Consumption


Fuel Totals - Untitled, Building 2
EnergyPlus Output
1 Jan - 31 Dec, Monthly
Licensed
Electricity
Gas
Generation (Electricity)
70000
60000
50000
40000
30000
20000
10000
0
Fuel (kWh)
2002
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan 2002
Month

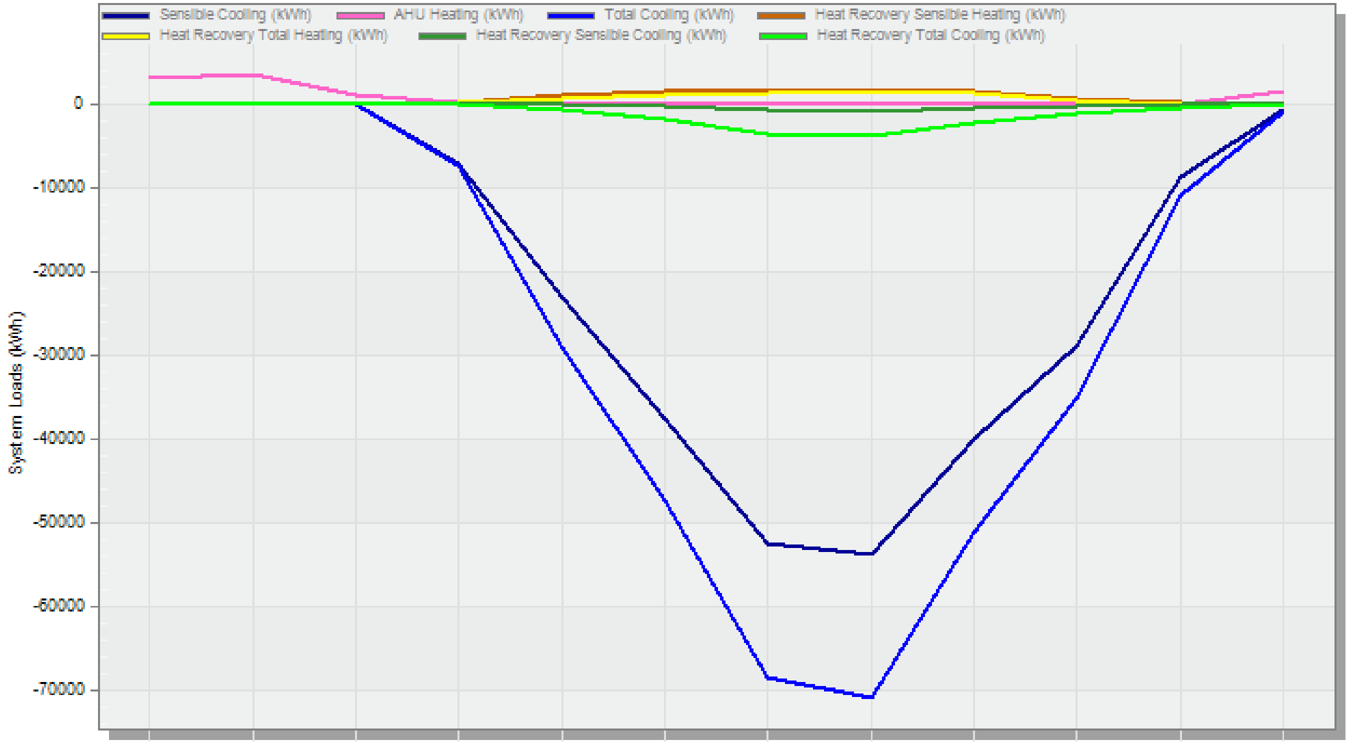
Fuel Totals

- Untitled, Building 2

EnergyPlus Output

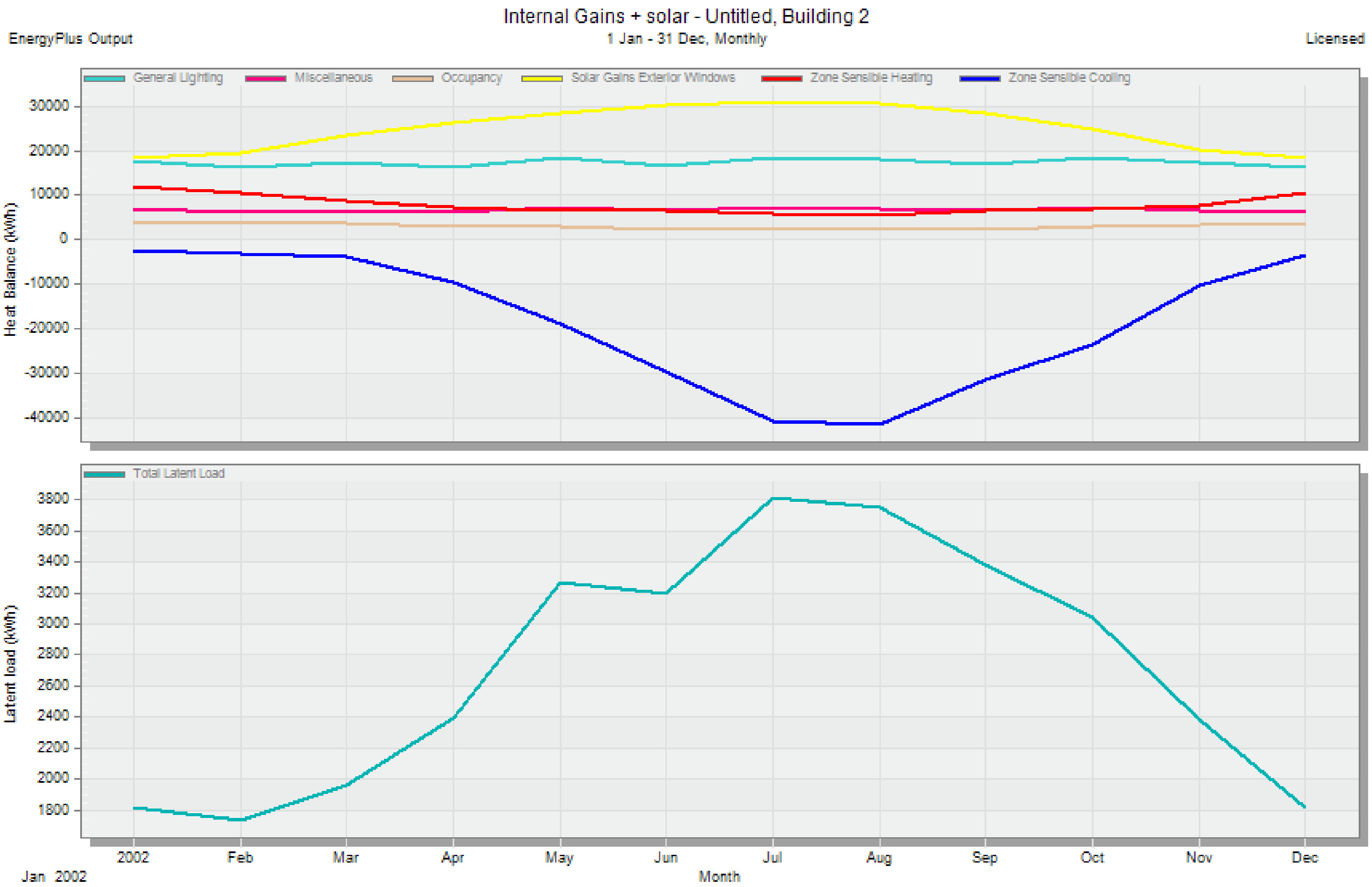
1 Jan - 31 Dec, Monthly

Licensed



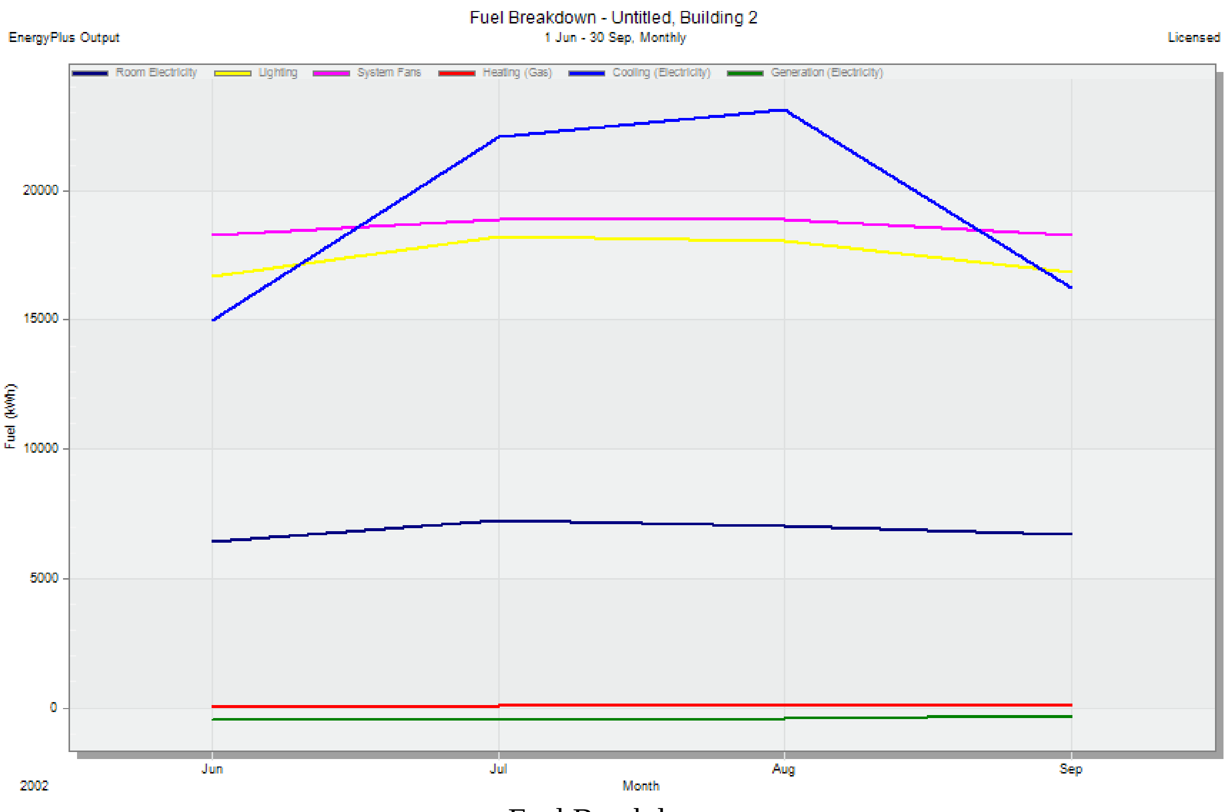
Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sensible Cooling (kWh)	0.00	-1.78	0.00	-6975.88	-23005.66	-37571.62	-52543.25	-53837.75	-39946.11	-28984.69	-8626.63	-598.39
AHU Heating (kWh)	3159.16	3591.09	1186.12	285.60	0.00	40.53	86.45	119.68	46.63	4.90	70.64	1613.02
Total Cooling (kWh)	0.00	-1.90	0.00	-7373.32	-29103.68	-47298.49	-68520.80	-70931.82	-51199.04	-35023.80	-10768.74	-886.90
Heat Recovery Sensible Heating (kWh)	0.00	0.00	0.00	355.07	1224.54	1747.32	1753.41	1675.93	1704.49	745.50	206.90	17.56
Heat Recovery Total Heating (kWh)	0.00	0.00	0.00	351.45	724.35	1284.02	1443.63	1304.75	1401.46	521.50	126.87	11.33
Heat Recovery Sensible Cooling (kWh)	0.00	0.00	0.00	-21.87	-20.76	-248.42	-633.08	-758.85	-311.33	-203.55	-31.65	0.00
Heat Recovery Total Cooling (kWh)	0.00	0.00	0.00	-26.70	-488.62	-1620.59	-3444.30	-3751.00	-2120.63	-979.38	-277.77	-0.01

System Load

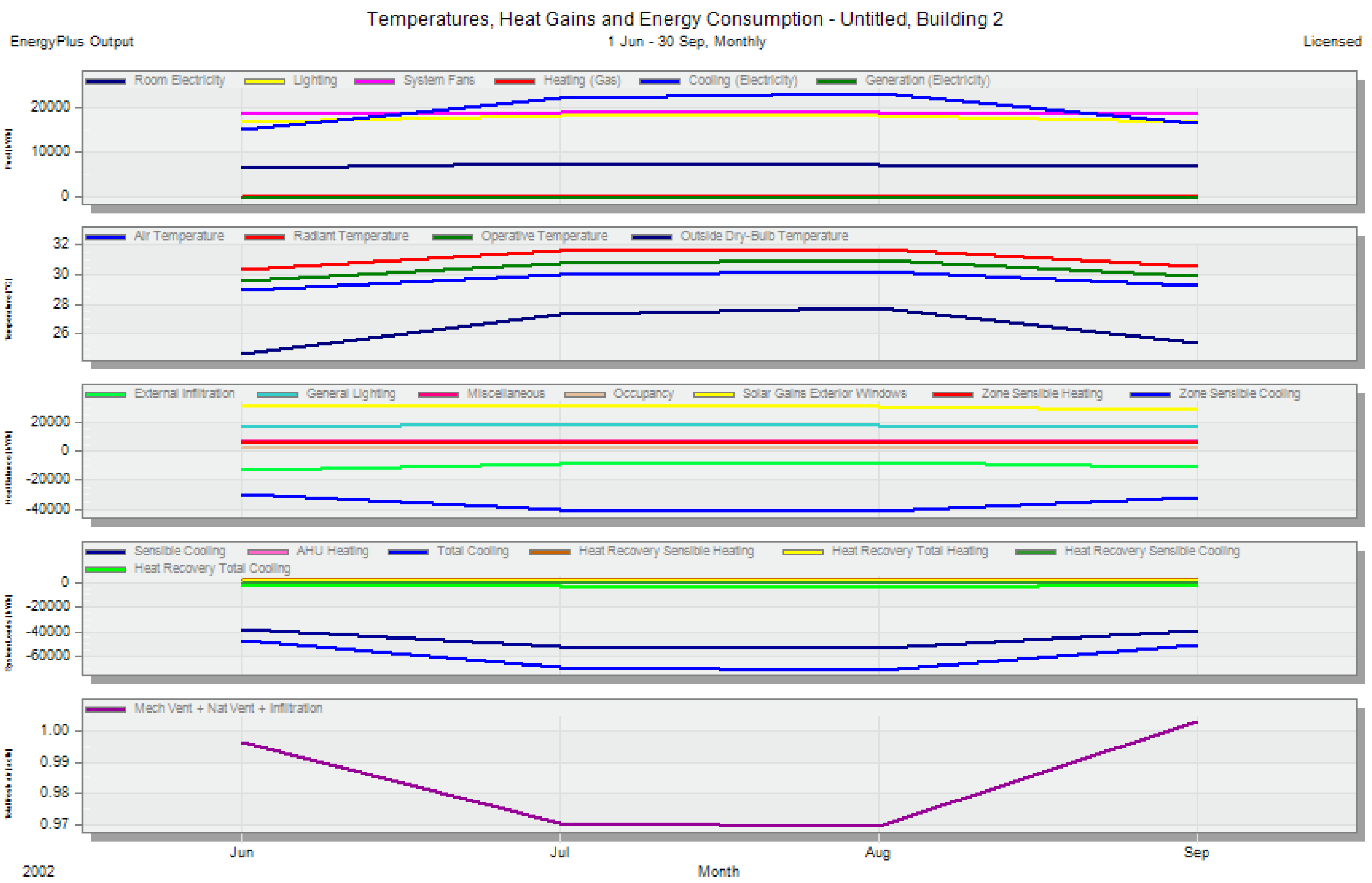


Internal Gains

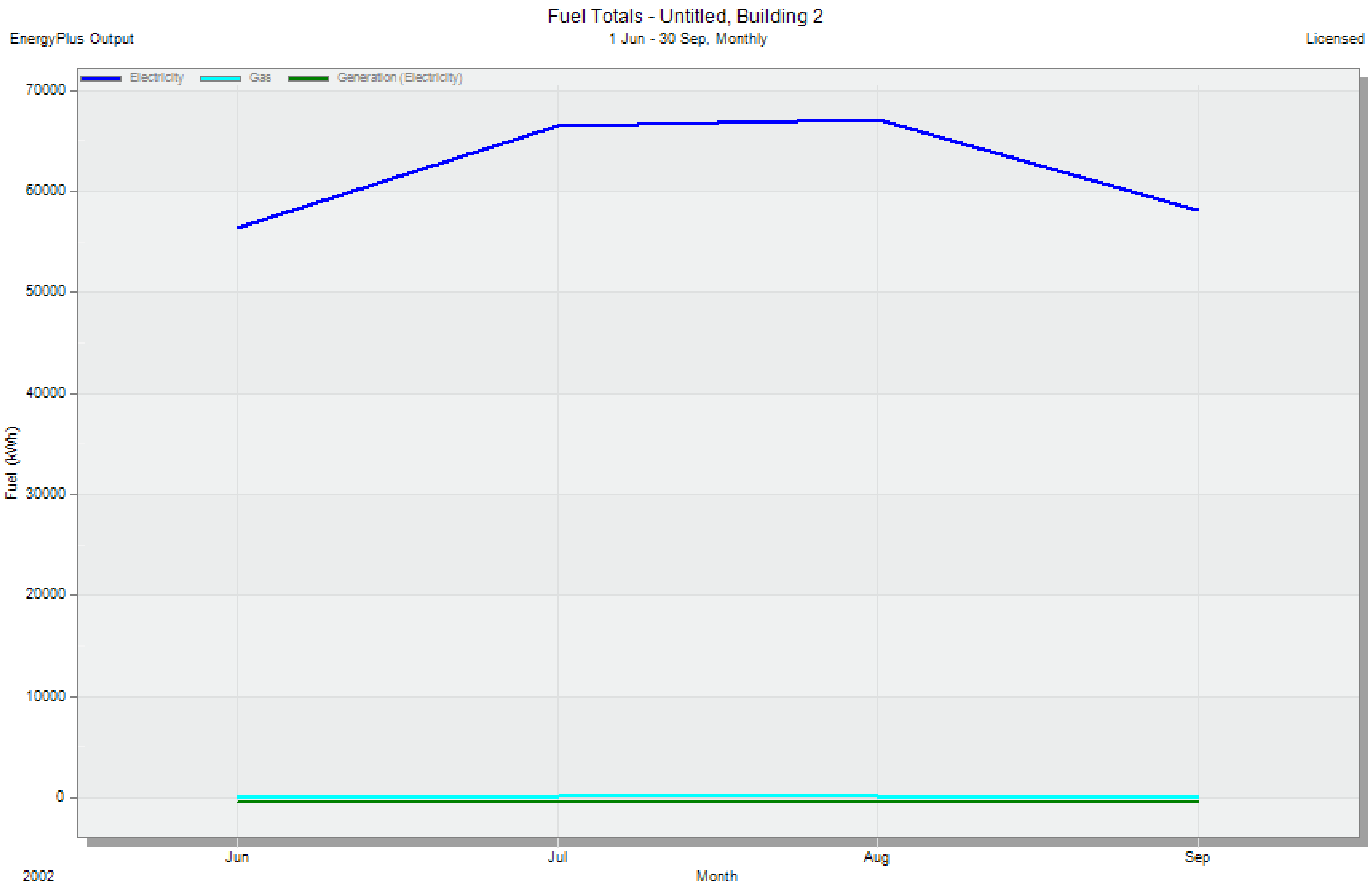
Appendix N: Colored Building Simulation After Integrated PV Panels in Vertical Shading Northwest Facade from (June -September)



Fuel Breakdown



Temperature, Heat, Gains and Energy Consumption


Fuel Totals - Untitled, Building 2
EnergyPlus Output
1 Jun - 30 Sep, Monthly
Licensed
Electricity
Gas
Generation (Electricity)
70000
60000
50000
40000
30000
20000
10000
0
Fuel (kWh)
Jun
Jul
Aug
Sep
2002
Month

Fuel Totals