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PCM Application-Effect on Energy Use and IA Temperature

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Abstract

This thesis work intends to investigate the variation in the energy use of the building and the IA temperature difference while using Phase change material (PCM) on different building components. The software used for simulation of the defined model is WUFI Plus: program allows inputting various data (different geometry of model, calculations can be done on various climate condition and different design condition of building assembly and inner load).

The PCM applied for simulation is DuPont Energain that consists of paraffin wax. The use of PCM in a design helps to stabilize IA temperature and keep it constant along the day profile for creating more comfortable thermal environment.

Energy demand is another important aspect in building design that is largely effected by the design condition and the parameters of component chosen for the model.

This thesis prioritizes the IA temperature and energy demand factors and uses WUFI Plus to simulate a standardized building model and checks the effect of PCM application on these factors.

Acknowledgment

I would like to take this opportunity to express a sincere gratitude to my supervisor, Professor Arild Gustavsen. This thesis work would not have been possible without your invaluable suggestions and your continuous encouragement throughout this period of hard work. I solely thank you for making the completion of this thesis possible.

I would like to thank Matthias Haase for making all the materials available to me and for his untiring responses to all my queries. I cannot miss to mention Mr. Thomas Haavi of SINTEF and the Fraunhofer-Institute of Building Physics, Holzkirchen for providing me a license to the software and also for solving my so many problems regarding the program use.

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Thank you

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Preface

This thesis report written on the title- PCM application- Effects on energy use and IA temperature is a work of theoretical review and experimental results of the simulation using WUFI Plus. The aim of this study is to evaluate the possible impact of using PCM on the energy demand of the building and IA condition. It also looks into the efficiency of PCM when applied to different building component.

The report is composed as 5 chapters.

First chapter includes the ***Introduction and liiterature review***. It relates to the human thermal comfort required in the building. The thermal energy storage (sensible heat storage and latent heat storage) in building can help increase the thermal comfort by using lesser energy. PCM is a LHS material that can be applied in building component. Hence chapter 1 includes about all this and also explains a little about WUFI Plus, the software used for simulation.

Chapter 2 is the ***Description of base case***. In this chapter, a detailed description of all the components, inner loads and design condition applied to model of simulation is done. The description of model used for simulation here is taken from the SINTEF dwelling box. The SINFTEF dwelling box follows the specification and standard for a small residential unit.

Chapter 3: ***Simulation and results***, shows different cases of simulation of the defined base case. In this part of the report, lots of different simulations are done by applying PCM on various components of the explained case and the results of such simulation is presented in various figures and graphs.

Chapter 4 comprises of ***Comparison and Discussion* of the results** obtained by the simulation. The results are further discussed here to make comparison of different cases used on simulation.

Chapter 5: ***Conclusion and Further works*** – the results of simulation and discussions are concluded in this chapter. Finally some opinion about the possibilities to further this work is brought up at the end of report.

Chapter-1

1.0. Introduction and Literature review

1.1 Comfort in building

Human comfort in a building is a foremost important consideration in building design. Comfort in building depends on various factors, design and use of building, nature and no of occupants in building, topographical location of building and various design selection as heating and cooling systems in building, mechanical and natural ventilation system etc.

Comfort condition in a building is a state where the users, the occupants of the building have a feeling of coziness. The comfort condition cannot be defined as any specific term as it varies according to the need of user and according to surrounding condition. As for example, requirement of a man working out on a gym may vary to the requirement of someone studying at his study. They may require larger ventilation at gym for frequent exchange of air whereas proper lighting (natural or artificial) is more important at study than any other parameter. Other factors come only after the specific parameter on each case.

However there are few parameters that defines indoor environment and contribute for the comfort condition in the building. Some of such parameters are: acoustic, indoor air quality, visual comfort and thermal comfort. Each of these parameters effect on the health and productivity of the occupants and it is essential to achieve proper level of all of them for the well operation and success of the building.

Acoustics is a science of sound: it deals with level of sound insulation desired by building and what it offers. The comfort condition for acoustics depends on the function of the building and the number and behavior of the occupants using the building.

Air freshness is another important requirement for comfort in building. It is required that a building offers adequate flow of fresh air into the building and extracts out used stack air from the building. Air freshness is closely related to the temperature of the building and so is the thermal comfort.

Thermal comfort basically is to have the right temperature in living space. Among all, thermal comfort is often considered as one of the most important requirement to ensure comfort for any building.

The simulations done further here are more related to Indoor air temperature changes and thermal comfort aspect of the building. Hence we will be referring to thermal aspect of building in more detail. The work here also looks into energy aspect of building. Energy conservation is an important consideration for proper performance of the building.

1.1.1 Comfort condition for Energy conservation

The energy related issues in a building are of course the secondary factor that has to be taken in account after fulfillment of the primary objective of the building that is to provide shelter, space and comfort. But still, creating a comfortable living environment might have a large impact on energy conservation.

The occupants of the building will react to any perceived discomfort by taking action to restore comfort. Such action sometime comes with the cost of energy. For example: using a shading device and turning on lights is a costly way to eliminate glare and overheating due to the presence of solar radiation. Similarly, opening a window in the winter due to overheating is also a costly way to alleviate discomfort. Therefore, it is important to recognize that a ‘low energy’ standard that increases occupant discomfort may be no more sustainable than one that encourages energy use.[1]

The energy consumption of any building is critically dependent on indoor air temperature which the building must maintain. The heat lost from the building, may that be through its surfaces or by ventilation depends on the difference in the inside and outside temperature. The sensitivity of occupants to indoor climate also has implication for how closely we need to control the environment and this again has the energy implication.[2]

1.2 Thermal comfort

Human thermal comfort as defined by ASHRAE is the state of mind that expresses satisfaction with the surrounding environment (ANSI/ASHRAE Standard 55[3]). Human body requires a certain level of temperature to be in a comfort and to be able to perform the activities. Human body produces energy by metabolizing food and most of this energy takes the form of heat. This metabolic heat produced by the body must be in balance for the body to be in comfort and be able to perform activities.

The internal temperature of the human body must always be kept within narrow limits at around 98.6°F (i.e. 37°C). Any small deviation in this temperature create severe stress, and illness, and a rise of 10 to 15°F or a drop of 20°F from this value can lead to death[4]. The human body has ability to balance its temperature by various means. This thermal balance is determined, on the one hand, by the “internal heat load” and on the other, by the energy

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[1] J.F. Nicol, Thermal comfort. In Solar thermal technologies for buildings, James & James Ltd, London (2003)

[2] . M. Santamouris, Solar thermal technologies for building, the state of the art, Chapter-8

[3] ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy

[4] Nobert Lechner, Heating, cooling, lighting Design methods for Architects, Chapter-4

flow (thermal exchange) between the body and the environment. The thermal exchange between the body and the environment takes place in four different ways: conduction, convection, radiation and evaporation (perspiration and respiration)[5].

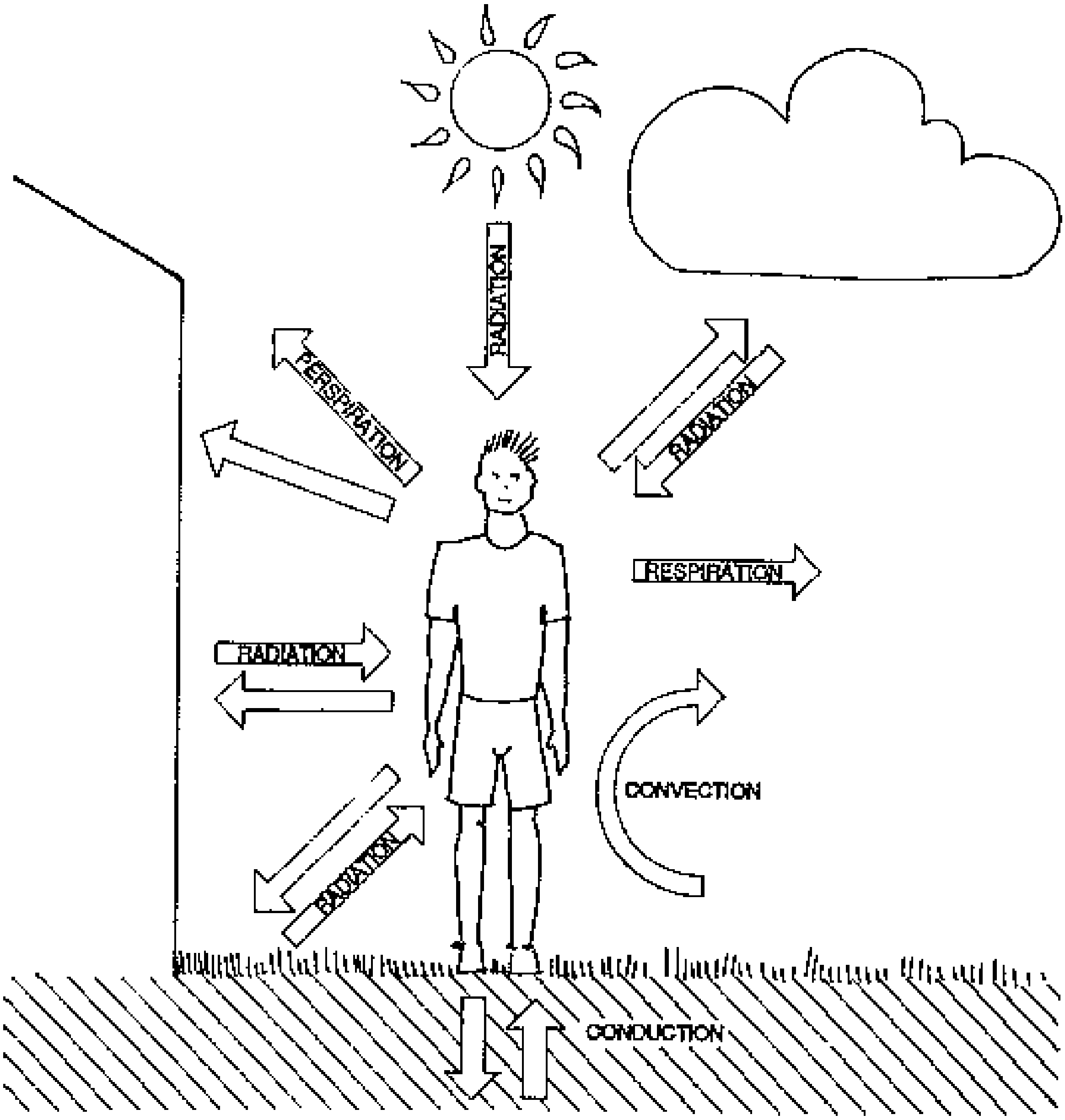

Figure 1: Thermal exchange by Human body[6]

Conduction *is the exchange of heat with the materials in immediate contact with the skin. Conduction usually accounts for only a small part of the whole heat exchange.*

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[5] Climate Responsive Building - Appropriate Building Construction in Tropical and Subtropical Regions Chapter 2.3 Human requirements regarding indoor climate

[6] Climate Responsive Building - Appropriate Building Construction in Tropical and Subtropical Regions Chapter 2.3 Human requirements regarding indoor climate

Heat exchange by ***convection*** *depends primarily on the temperature difference between the skin and the air and on air movement. It can, to a certain extent, be controlled by selection of proper clothing.*

Radiation *takes place between the human body and the surrounding surfaces. It depends mainly on the difference in temperature between the person's skin and the surrounding or enclosing surface.*

Evaporation *occurs in human body in the form of perspiration and respiration*

1.2.1 Factors affecting thermal comfort

After the thorough study of thermal comfort and their relation to human, the variables effecting thermal comfort can be grouped on different groups as follows[7]:

- Environmental factors:
    - **Air temperature** is the temperature of the air around the body. It determines the rate at which heat is lost to the air. The air temperature is given in degrees Celsius (°C) or degrees Fahrenheit (°F).
    - **Radiant temperature:** Thermal radiation is the heat that radiates from a warm object. Radiant heat may be present if there are heat sources in an environment. Radiant temperature has greater influence on heat gain of heat loss from the body. Sun, fire, furnaces, steam rollers, oven etc. are the examples of radiant heat source. Presence of any of such radiant heat source around the body may have large effect on comfort condition.
    - **Relative Humidity:** This is the ratio between the actual amount of water vapor in the air and the maximum amount of water vapor that the air can hold at that air temperature. Evaporation of skin moisture is largely dependent on the humidity of air. High humidity environments have a lot of vapor in the air, which prevents the evaporation of sweat from the skin and create discomfort in living as evaporation of sweat is one of the main method of heat loss in humans.
    - **Air Velocity:** It is the speed of air moving across the body. Air velocity affects the heat loss rate by both convection and evaporation. The air movement is likely to be useful for cooling of the surrounding. Still or stagnant air in indoor environments may cause people to feel stuffy and also lead to build-up odors. Moving air in warm or humid conditions can increase heat loss through convection without any change in air temperature and contribute to

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[7] http://en.wikipedia.org/wiki/Thermal_comfort

thermal comfort. Whereas in cold environment, small air movement may be perceived as draught. If the air temperature is less than skin temperature it will significantly increase convective heat loss

- Personal factors: - Metabolic rate

  - Clothing

Besides, there are other physiological factors as human habit of food and drink, body shape, state of health, activity age and gender that contributes on the consideration of thermal comfort. Activity is the most important of these factors that contributes on thermal parameters.

1.2.2 Thermal comfort zone

The optimum thermal condition is the situation in which a body temperature are held within the narrow ranges and in which the least extra effort is required to maintain the human body’s thermal balance. It is usually not possible to achieve maximum comfort condition but the house should be built to provide an indoor climate close to an optimum, within a certain range in which thermal comfort is still experienced. This range of comfort is called as comfort zone. Thermal comfort zone largely depends on the above mentioned factors of thermal comfort. As already mentioned earlier, the feeling of comfort inside a building depends on complex physical and physiological interrelationships that cannot be described easily. The comfort factors are not only affected by the metabolism of the human body but also by factors such as clothing and the activity of the people in the room., there is a certain range of condition for environmental factors in which most of the peoples sense the feeling of comfort.

Comfort condition values of environmental factors for human body:

- **Air temperature**: human body will lose heat to the environment below 98.8°F, and the process reverses (i.e. it gains heat) when temperature is above that. The comfort range of air temperature for most people ranges from 68°F in winter to 78°F in summer.

- **Radiant temperature**: the radiant temperature must be maintained close to air temperature as far as possible. Greater the difference between these two factors, higher is the comfort level.

- **Air velocity**: the comfortable range of air velocity is between 60 feet per minute (fpm) to about 200 fpm. The higher air velocity may result on draft and create discomfort.

- **Relative humidity**: relative humidity of a body should be maintained above 20 % all along the year, during summer this value should be below 60% and in winter it should be below 80%. The lower air humidity causes dryness of nose, mouth, ayes and skin and also result in the respiratory illness. Shrinkage of wood is also caused by low humidity. In contrary, high humidity reduces the evaporative cooling rate and contributes in the formation of skin moisture (sweat) which creates discomfort to body.

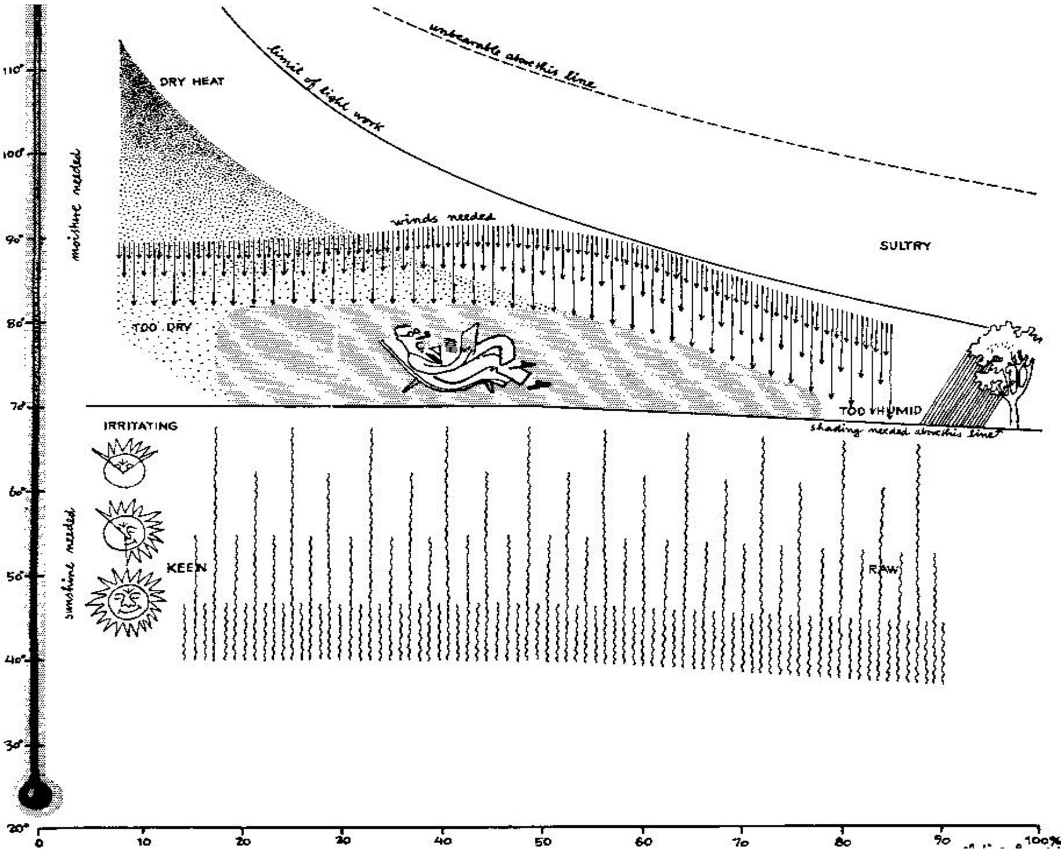

Figure 2: The Comfort Zone, Schematic bioclimatic index[8]

The shaded area in the center of the diagram shown is the thermal comfort zones. The chart indicates the zone where comfort is felt in moderate climate zones, wearing indoor clothing and doing light work. It also assumes that not only the air temperature, but also the temperature of surrounding surfaces lie within this range.

Thereafter the understanding of thermal behavior of human being and essence of thermal comfort in a building, this research work shall narrow its scope. We will be more discussing about the thermal energy storage on the building and their benefits in reduction of energy use on the building.

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[8] Victor Olgyay, "Design with Climate": bioclimatic approach to architectural regionalism; Fig 46

1.3 Thermal energy storage

Thermal energy storage (TES) can be defined as the temporary storage of thermal energy at high or low temperatures. The concept of thermal energy storage is not a new concept. They have been used to improve the energy conservation for centuries. Energy storage helps to improve performance of energy systems by smoothing supply and increasing reliability. For example, in the case of solar energy use, although the sun provides an abundant, clean and safe source of energy, the supply of this energy from the sun is periodic due to its diurnal and yearly cycles. The energy source from sun is intermittent, often unpredictable and diffused. The demand for energy, on the other hand, is also unsteady. Therefore the need for the storage of solar energy cannot be avoided to supply required energy when necessary. Storage of energy improves the energy efficiency and the higher efficiency would lead to energy conservation.

There are different methods to store thermal energy. Thermal energy storage can be stored and retrieved as a change in internal energy of a material as sensible heat, latent heat and also in thermo-chemical reactions or combination of these.

1.3.1 Sensible heat storage

Heating a liquid or a solid, without changing phase: This method is called sensible heat storage. In sensible heat storage (SHS), energy is stored or extracted by heating or cooling a liquid or solid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of stored thermal energy depends on the specific heat of the medium, the temperature change and the amount of storage material.

A variety of substances have been used for SHS. These include liquids like water, heat transfer oils and certain inorganic molten salts, and solid like rocks, pebbles and refractory. In the case of solids, the material is invariably in porous form and heat is stored or extracted by the flow of a gas or a liquid through the pores or voids.

1.3.2 Latent heat storage

Latent heat storage is based on the heat absorption or release when a storage material upon heating or cooling undergoes a phase change from solid to liquid or liquid to gas or vice-versa. The main principle of LHS is that when heat is applied to the material, it changes its phase from solid to liquid by storing the heat as latent heat of fusion or from liquid to vapor as latent heat of vaporization. When the stored heat is extracted by the load, the material will again change its phase from liquid to solid or from vapor to liquid.

The amount of energy stored in LHS depends upon the mass (m) and latent heat of fusion (λ) of the material. Heat storage through phase change has the advantage of compactness, since the latent heat of fusion of most materials is very much larger than their enthalpy change for 1 K or even 0 K. For example, the ratio of latent heat to specific heat of water is 80, which means that the energy required to melt one kilogram of ice is 80 times more than that required to raise the temperature of one kilogram of water one degree Celsius.

Amongst two thermal heat storage techniques, latent heat thermal energy storage is particularly attractive due to its ability to provide high-energy storage density and its characteristics to store heat at constant temperature corresponding to the phase transition temperature of PCM. LHS can be accomplished through solid–liquid, liquid–gas, solid–gas and solid–solid phase transformations. However the solid–liquid and solid–solid transitions are of practical interest. The solid–gas and liquid–gas systems are of limited utility because of the large volumes required for such systems. Of the two practical systems, the solid–liquid system is the most studied and most commonly commercially available Thermal storage can be used to store cool or hot energy that is either available freely or that can be produced very efficiently only at specific times.

1.4 Phase Change Materials, PCM

A Phase Change Material, PCM is a substance with high heat of fusion. They have capacity of melting or solidifying (change their state) at a certain temperature and while doing so, they store or release a large amount of energy (latent heat). Unlike conventional sensible thermal storage methods, PCMs provide much higher energy storage densities and the heat is stored and released at an almost constant temperature. PCMs can be used for both active and passive space heating and cooling systems.

The concept of heat storage (SHS and LHS) can be compared on the Figure 3 which shows the energy storage by any medium. Blue line on the graph is SHS which increases in proportion to the increase of temperature whereas red line is a LHS which increases abruptly at the point of phase change.

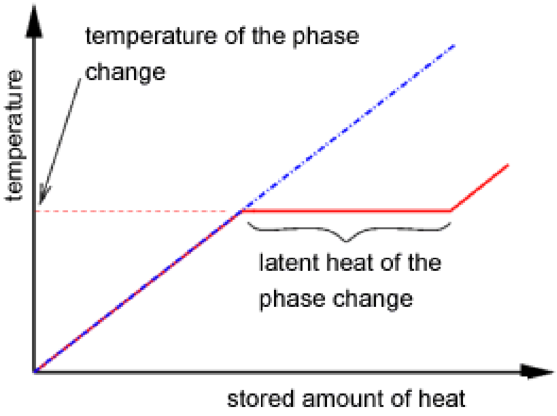

Figure 3 : Thermal storage on PCM

1.4.1 Properties of PCM

PCM requires fulfilling some criteria to be used as Latent heat storage materials. Some of the major criteria to fulfill can be categorized as follows:

Physical properties:

(i) Melting temperature in the desired operating temperature range

(ii) High latent heat of fusion per unit volume
(iii) High specific heat, high density and high thermal conductivity
(iv) Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem
(v) The material should passes properties to avoid super cooling
(vi) Cheap and easy availability

Chemical properties

(i) Chemical stability
(ii) Complete reversible freeze/melt cycle
(iii) No degradation after a large number of freeze/melt cycle
(iv) Non-corrosiveness, non-toxic, non-flammable and non-explosive materials

1.4.2 Classification of PCM

A large number of PCM are available that are produced to perform in a variety of temperature ranges. But all the materials do not have all the required properties to be an ideal thermal storage media, therefore one has to use the available materials and try to make up for the poor physical property by an adequate system design. For example metallic fins can be used to increase the thermal conductivity of PCMs: super cooling may be suppressed by introducing a nucleating agent in the storage material and incongruent melting can be inhibited by use of suitable thickness.

There are a large number of organic, inorganic and eutectic materials, which can be identified as PCM from the point of view of melting temperature and latent heat of fusion. The general classification of PCM can be done as shown on the figure below.

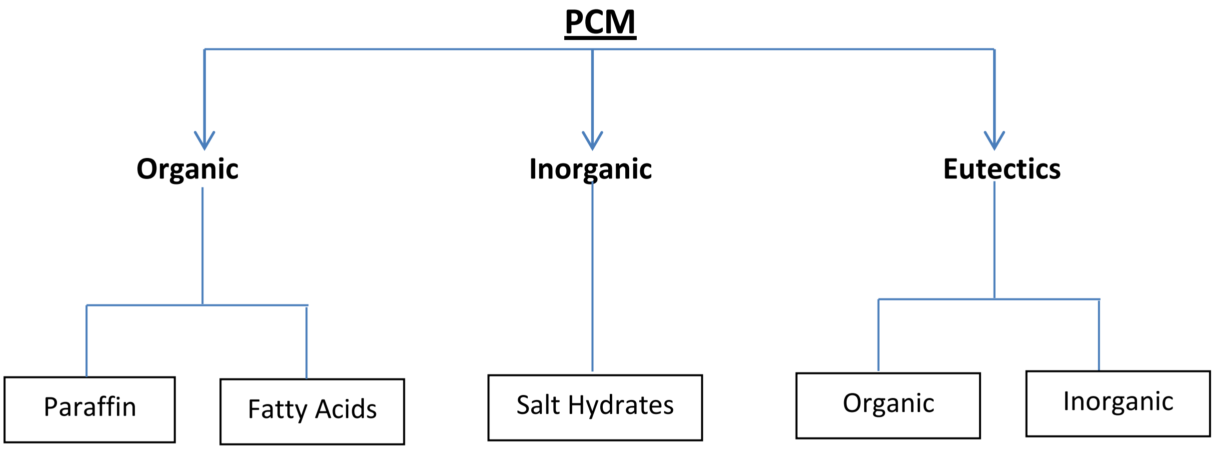

Figure 4: classification of PCM

Each of these types of PCM has its own specific characters, advantages and disadvantage.[9]

Table 1: Advantages of Different types of PCM

Organic	Inorganic	Eutectics
• Available for larger temperature range • Less super cooling while freezing • Congruent melting • Self-nucleating • Compatible with conventional construction materials • No segregation • Chemically stable • High heat of fusion • Safe and non-reactive • Recyclable	• High volumetric latent heat Storage capacity • Low cost • Easily available • Sharp melting point • Higher thermal conductivity • High heat of fusion • Low volume change • Non-flammable	• Eutectics have sharp melting point similar to pure substance • Volumetric storage density is slightly above organic compounds

Disadvantages of PCMS

Table 2 : Disadvantages of PCMs

Organic	Inorganic	Eutectics
• Due to its low thermal conductivity in their solid state, high heat transfer rates are required during the freezing • Volumetric latent heat storage capacity is low • Flammable. This can be easily alleviated by using with a proper container • Due to cost consideration, only technical grade paraffin may be used which are essentially paraffin mixture and are completely refined of oil	• Change of volume is very High • Super cooling is major problem in solid-liquid transition • Nucleating agents are needed and they often become imperative after repeated cycle.	• Only limited data is available on thermo physical properties as the use of these materials are very new to thermal storage application.

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[9] "Phase change material-based building architecture for thermal management in residential and commercial establishments" by A. Pasupathya, R. Velraja, R.V. Seeniraj. Pg: 44

1.4.3 Building Application- PCM

PCMs can be incorporated in building design in various forms to enhance the heat storage capacity of the materials. In general, PCMs can be encapsulated in building materials such as concrete, gypsum wallboard and applied to various building components: ceiling or floor to increase their thermal storage capacity. They can either capture solar energy directly or thermal energy through natural convection and store them as LHS. This capacity of PCM to store thermal energy can be used in a number of ways, to make the energy system more efficient and cheaper. PCMs are also very useful in providing thermal barriers or insulation to achieve thermal comfort.

The three main areas that PCM has been introduced in building design are:

- PCM in Walls- Wallboard and concrete impregnation
- PCM in Components other than walls - window shutters and double glazing
- PCM in heat and cold storage units - e.g. under-floor heating systems, night time cooling ventilation systems

The first two are passive systems, where the heat or cold stored during melting or freezing is automatically released when indoor or outdoor temperatures rise or fall beyond certain temperature. The third one is active system, where the stored heat or cold thermally separated from the building by insulation and is only when it is demanded.

Because of application potential in building in all above forms, researches has been done continuously on PCM products and various commercial PCMs have been developed with the properties that suite their properties for building application.

1.4.4 Some Commercial PCM

Table 3: Some PCM products with their properties

PCM name	Type of product	Melting temperature (° C)	Heat of fusion (kJ/kg)
Astorstat HA17 Astorstat HA18	Paraffin and waxes	21.7–22.8 27.2–28.3	
RT26 RT27	Paraffin	24-26 28	232 206
Climsel C23 Climsel C24	Salt hydrate	23 24	148 108
STL27	Salt hydrate	27	213
E23	(mixture of non-toxic eutectic solution	23	155

1.5 DuPont™ Energain®

A detailed overview of all the physical and thermal properties are listed here for this specific PCM product as we are later going to use DuPont™ Energain® in our simulation. DuPont™ Energain® is one of the commercially available PCM: it contains a PCM with a melting point around 22 °C. Because it has a melting temperature in the operating range of buildings, it can be used to enhance the thermal inertia inside.

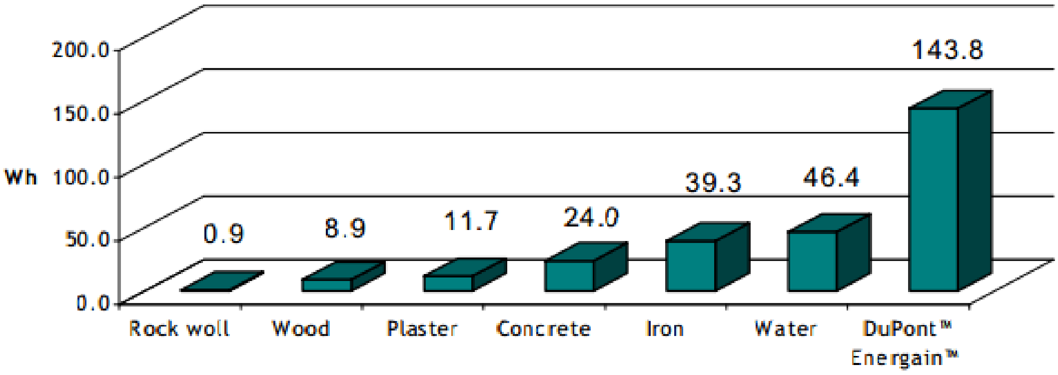

Figure 5: heat exchange for different materials between 18- 24 C

The graphical figure 5 shows a comparison of total heat exchanged for 5mm thickness of different materials at a temperature between 18- 24 °C.

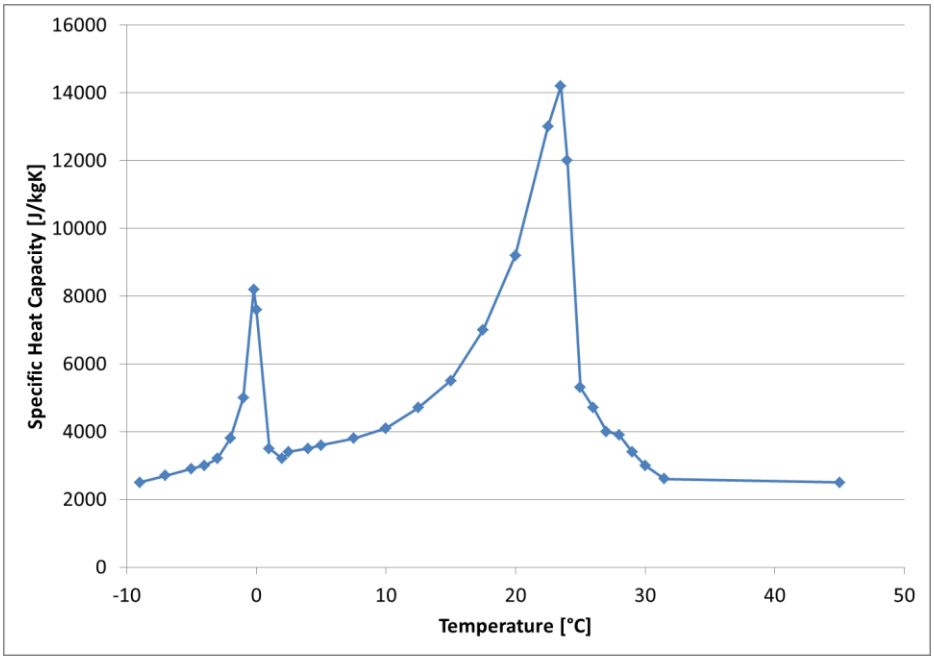

Figure 6: Specific heat Capacity of DuPont Energain

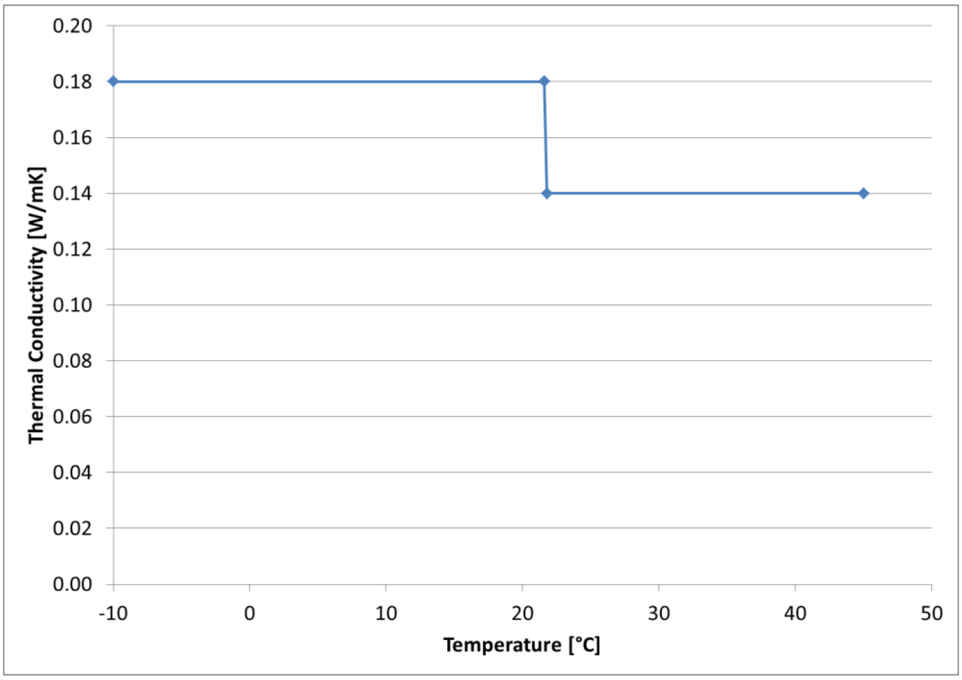

Figure 7: Thermal Conductivity graph

1.5.1 Description of DuPont Energain product[10]

Table 4: Description of DuPont Energain[11]

Descriptive Properties	Unit	Value
Thickness	mm	5.26
Width	mm	1000
Length	mm	1198
Area weight	Kg/m2	4.5
Aluminum thickness(sheet)	µm	130
Aluminum thickness(edges)	µm	75

Table 5 : Thermal and Physical Properties

Thermal Properties	Test method	Unit	Value
Paraffin loading	Comparative test by DSC	%	60
Melt point (paraffin)	DSC method (1°C/min)	°C	21.7
Latent heat storage capacity	DSC method (1°C/min)	kJ/kg	> 70
Total heat storage capacity (Temperature range 14°C to 30°C)	DSC method (1°C/min)	kJ/kg	> 170
Physical Properties			
Aluminium sheet delamination force	Internal DuPont test method	N/cm	> 20
Conductivity solid	BS EN 12667-2001	W/(m.K)	0.18
Conductivity liquid	BS EN 12667-2001	W/(m.K)	0.14
Flash Point (paraffin)	ASTM D56	°C	148

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[10] www.energain.dupont.com

[11] www.2DuPont.com/Products_Services/en_US/index.html

Table 6 : Product Description

The panel is a fine mixture of ethylene based polymer (40%) designed by DuPont and paraffin wax (60%) laminated on both sides with a 130 µm aluminium sheet. The edges are closed with a 75 µm aluminum tape.

Table 7 : Reaction to Fire

Single-flame source test	EN 11925-2	Class E
Surface spread of flame test	BS476 part 7	Class 1
BS476 part 7 & BS476 part 6 (behind plasterboard)	Building Regulations (AD B)	Class 0

Table 8 : Durability

Predicted to be durable for the life-time of a building
Chemically inert with most materials

1.6 WUFI Plus

WUFI is a simulation program for calculating the heat and moisture transfer within the building elements. It is a German language simulation program which stands for "Wärme und Feuchte instationär" (transient heat and moisture). The software can calculate the transient development of temperature and moisture. The application focuses on forecasting possible moisture damage or humidity-dependent heat losses caused by indoor climate and natural weather effects. The features of software were gradually expanded to form complex software for simulating complete buildings including the heating systems and ventilation. WUFI 1D, WUFI 2D, WUFI Plus and WUFI PRO etc. are some of the forms of advanced software now in use.

WUFI Plus is a room climate model which focuses on calculating the thermal behavior of the building taking into account hourly outdoor climate values, interior thermal loads, various set-point temperatures and ventilation strategies as well as adjusted system technology. With the building simulation software WUFI Plus the hygric and thermal ratios in a building, in its perimeter and their interaction can be calculated and quantified along with the energy demand and consumption of system engineering.

Building models can be produced on WUFI Plus by using wizards, the boundary conditions can be specified and simulations conducted. Simulation results such as the indoor temperature are graphically depicted and users are provided with support in interpreting the results. The energy consumption ratios in a building are affected by climatic conditions on location and also by system engineering and loads resulting from use or rather user behavior. Outside influences are the climatic conditions inside influences are loads depending on type of use, user ratio and the user behavior.

In order to reduce the building energy consumption in an effective manner, the interaction between the building, usage and system technology must be taken in account during the planning. A time-dependent simulation that incorporates all significant boundary conditions also helps when considering decisive details in the building operation, including the ventilation strategies, the dynamics caused by thermal storage effects and strategies to prevent overheating in summer. Experimental analyses, which are expensive and time consuming today, can be avoided because WUFI Plus allows easy and quick changes in construction and assembly, the input of different boundary conditions as well as variances of parameters like material characteristics.

WUFI Plus offers the following performance:

- The transient heat and moisture transports are calculated connected. This happens in arbitrary time steps within an arbitrary simulation period. The calculation is done with the finite volumes method.
- The simulation building can be modeled easy with aid of the Building Wizard. For buildings with more complex shapes there is the possibility to input a script file. Numerous assemblies and materials are already deposited in the accordant databases and can be assigned to the components of the simulation building. The databases can be expanded arbitrary.
- The outside conditions are affected by the climate at the location. The data for the climate can be realistic, of synthetic constitution or completely generated artificial. WUFI Plus comes with climate files (TRY) for many worldwide locations. The specifications about heating, cooling and ventilation can be done manual and regulated daytime- and season-depending. So the influence on heat and moisture behavior and room climate can be included to the calculation. And contrary the capacity of the system for comfortable conditions can ascertained.
- The results of a simulation are output as graph or in tabulation. To output the results as ASCII is also possible. For the single components the calculation results can be viewed as video.

WUFI Plus aims at referees, building planners, engineers, architects and experts in the fields of moisture engineering and room climate.

Chapter 2

2.0 Description of Model

A base case was prepared for simulation in WUFI Plus. All the dimensions for this model, heated areas, and opening sizes were taken from the dimension of a SINTEF box, a standard specified for a residential unit. The inputs for inner loads and occupancies and the design conditions for the base case was taken from the Norwegian standards NS 3031 and the U-values of all the components were taken from Norwegian Building code. Weather data for weather in Oslo was considered for simulating this base case.

Inputs and data's for WUFI simulation of SINTEF Dwelling

Description of the Model

Total Area - 10 m X8 m (each floor)

Floor height - 2.7m (GF)

-2.4 m (FF)

Heated floor Area - 160 m^2

Heated volume - 408m^2

Climate data for Oslo is taken in account.

2.1 BUILING COMPONENTS

All the Building components in the simulation are considered to be light weight timber framed structure. Each element is chosen such that the building component fulfills the requirement of Norwegian building code. All the building components with all their elements and thermal properties are listed below.

2.1.1 Ground Floor

Ground floor constitutes of a homogenous layers of different elements chosen from the WUFI Plus material database. Timber based boards and insulations results on the floor construction with thermal Resistance value of 6.482 m^2K/W and Heat transfer coefficient, U-value of 0.15 W/m^2K. Different material layers on the floor and their properties are as listed on the table below:

Table 9: Components on Ground floor

S.no	Material Layers (From top to bottom)	Density Kg/m^3	Heat Capacity J/kg	Thermal conductivity W/mk
1.	60 minute Building Paper	280	1500	12
2.	Mineral wool	60	850	0.04
3.	PE- Membrane 0.15 mm	130	2200	2.2
4.	Wood fibre board, hard	800	1700	0.18
5.	Oak, radial	685	1500	0.13

2.1.2 Floor Slab

Intermediate floor between the stories is 0.3 m thick and has thermal Resistance value of 5.475 m^{2}K/W and U-value of this floor is 0.17 W/m2K. Materials of floor are chosen such that the construction is light weight structure. Different layers on floor construction constitutes of following layers:

Table 10: Floor Slab Assembly between the floors

S.no	Material Layers (From top to bottom)	Density Kg/m^3	Heat Capacity J/kg	Thermal conductivity W/mk
1.	Gypsum Board	850	850	0.2
2.	Air layer 50 mm	1.3	1000	0.28
3.	Mineral wool	60	850	0.04
4.	Wood fibre board, hard	800	1700	0.18
5.	Oak, radial	658	1500	0.13

2.1.3 Wall Assembly

Wall structure is lightweight timber framed wall of thermal resistance 5.37 m^{2}K/W. Heat transfer coefficient value of the chosen wall assembly fulfills the requirement of Norwegian Building code, U-value of wall is 0.18 W/m^{2}K. Thermal bridges are not taken in consideration in any building component during simulation. Wall composites of following layers with the thermal values as mentioned on the table below.

Table 11: Components on wall assembly

S.no	Material Layers (From outside to inside)	Density Kg/m^3	Heat Capacity J/kg	Thermal conductivity W/mk
1.	Hardwood	650	1500	0.13
2.	Air layer 25mm	1.3	1000	0.155
3.	60 minute Building Paper	280	1500	12
4.	Mineral Wool	60	850	0.04
5.	PE-Membrane 0.15 mm	130	2200	2.2
6.	Gypsum Board	850	850	0.2

2.1.4 Roof Construction

Roof has the Thermal Resistance value of- 7.569 m^2K/W. and heat transfer coefficient of 0.13 W/m^2K. The roof assembly is 0.315 m thick with all its layers.

Table 12: Components of Roof slab construction

S.no	Material Layers (From outside to inside)	Density Kg/m^3	Heat Capacity J/kg	Thermal conductivity W/mk
1.	PVC Roof Membrane	1000	1500	0.16
2.	Mineral wool	60	850	0.04
3.	PE- Membrane 0.15mm	130	2200	2.2
4.	Mineral wool	60	850	0.04
5.	Gypsum Board	850	850	0.2

2.1.5 Window Parameters

The window area is as per the area of windows on SINTEF dwelling model. Total Window Areas is 32 m^2 distributed along all the surfaces. Each of the North and South façade has 9 m^2 of opening and there is a 7 m^2 window on both east and west façade. The type of window is Triple Glazing window with the U-value of 1.2 W/m^2k.

In the simulation of this base case, it is considered that there is no solar shading on any window. Other window parameters are as shown on the table below:

Table 13: Window parameters

U- value (W/m^{2}K)	1.2
Frame factor [-]	0.7
SHGC Hemispherical [-]	0.51
Emissivity of external surface [-]	0.85

SHGC (Solar heat gain coefficient) is a fraction of solar heat that enters through a window into the indoor environment. In simpler words, SHGC measures how well a window blocks heat form the sun. Lower a window's SHGC, the less solar heat transmits.

2.2 Inner loads and occupancy

Internal load for occupancy	-1.5 W/m2 (NS 3031)
Total internal load	- 240 W (Convective heat- 160W and radiative heat- 80 W)
Lighting and equipment	- 600 W

2.3 Design conditions

- Climate data for Oslo
- Minimum temperature at working hours 21° C
- Minimum temperature outside working hour 19° C
- Maximum temperature 27° C
- No Shading devices
- General heating system and mechanical ventilation system with 80% heat efficiency
- No cooling System has been applied

2.4. Base Cases

2.4.1 Base Case A

The above mentioned case of material assembly and design condition makes a base case for the simulation on WUFI Plus all along the report. This first simulation of Base case A is done without making any changes to mention data and condition.

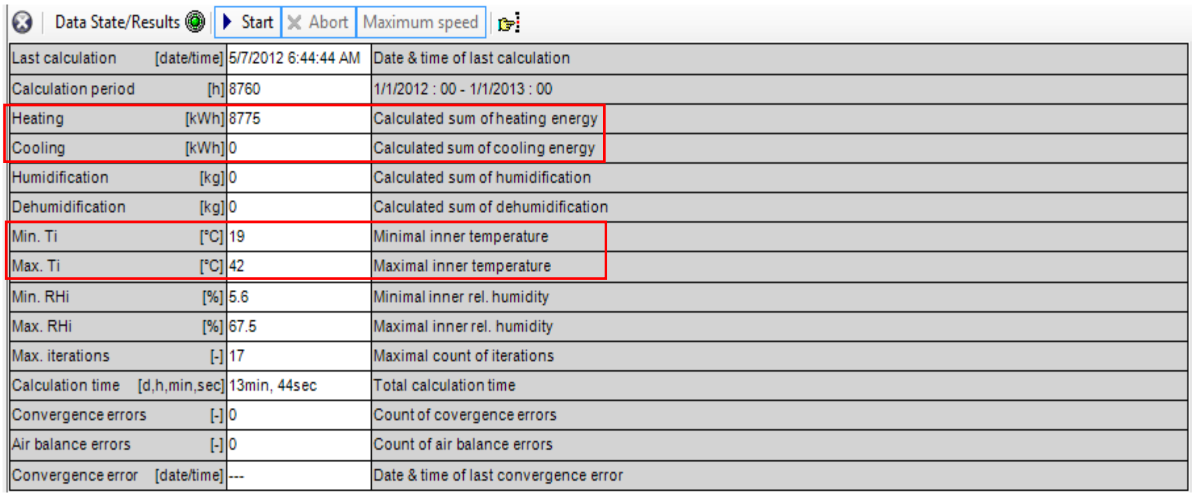
Output of Simulation

The output in WUFI Plus can be obtained in the following mentioned forms. The basic results of simulating Base case A is shown in this chapter and detailed discussions are illustrated in following chapter.

The result here shows for the thermal calculation of Base case A with WUFI Plus.

Data state and result

All the important inputs and outcome of the simulation are shown on the Data state/Results tab that is displayed on the bottom of WUFI Plus screen. The entities to be displayed on this table can be chosen by the user. Below is such table form WUFI Plus, showing the results of the case explained earlier.



Last calculation	[date/time]	5/7/2012 6:44:44 AM	Date & time of last calculation
Calculation period	[h]	8760	1/1/2012 : 00 - 1/1/2013 : 00
Heating	[kWh]	8775	Calculated sum of heating energy
Cooling	[kWh]	0	Calculated sum of cooling energy
Humidification	[kg]	0	Calculated sum of humidification
Dehumidification	[kg]	0	Calculated sum of dehumidification
Min. Ti	[°C]	19	Minimal inner temperature
Max. Ti	[°C]	42	Maximal inner temperature
Min. RHi	[%]	5.6	Minimal inner rel. humidity
Max. RHi	[%]	67.5	Maximal inner rel. humidity
Max. iterations	[-]	17	Maximal count of iterations
Calculation time	[d,h,min,sec]	13min, 44sec	Total calculation time
Convergence errors	[-]	0	Count of covergence errors
Air balance errors	[-]	0	Count of air balance errors
Convergence error	[date/time]	---	Date & time of last convergence error

Figure 8; Results of Simulation

The highlighted entities on the list of results are mainly discusses throughout the thesis. The results of simulation for this particular case can be compiled as following numbers.

Table 14: Results of Simulation

Heating demand	8775 kWh
Cooling demand	0 (no cooling implied)
Maximum IA temperature	42 °C
Minimum IA temperature	19 °C

The whole simulation is described completely and can be reconstructed as a report. All the general set up of the project can be found on the results and output tab in WUFI. A set of such report is attached as Annex I at the end of the report.

Graphs:

The results of calculation are also documented in graphical forms. Shown below are some of the results, of the above explained model in graphical manner.

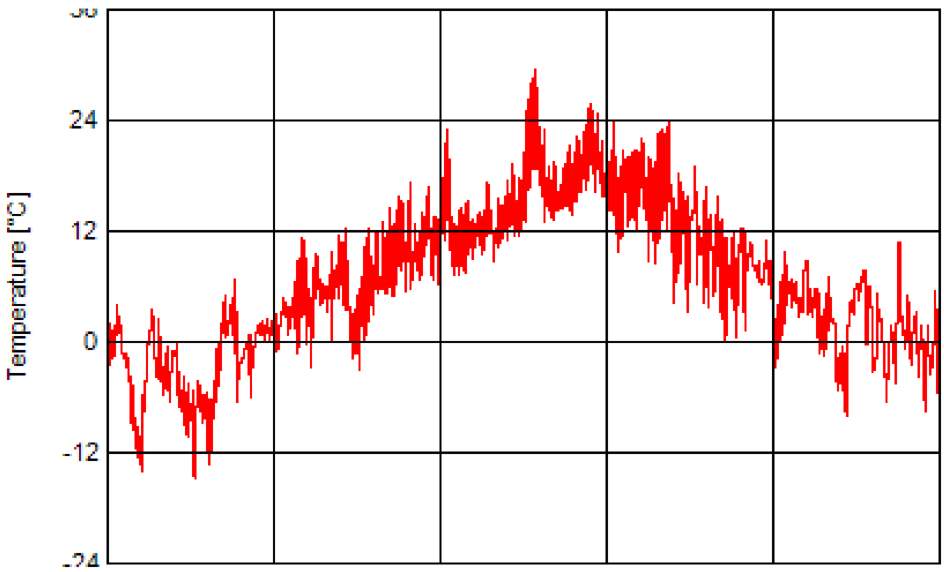


Figure 9 : External temperature variation for whole year

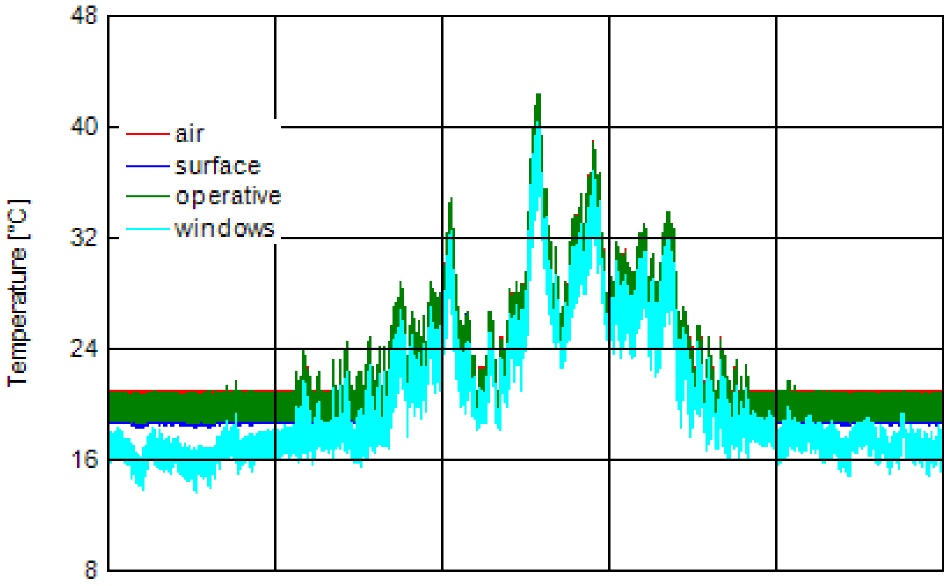


Figure 10 : Indoor temperature

Figure 9 is the outdoor climatic condition of the case. The temperature measure data is obtained for every 0.1 hour or any selected time period.

Similarly, Figure 10 is the representation of indoor temperature fluctuations. The indoor temperature graph shows indoor air temperature, surface, and operative and window temperature.

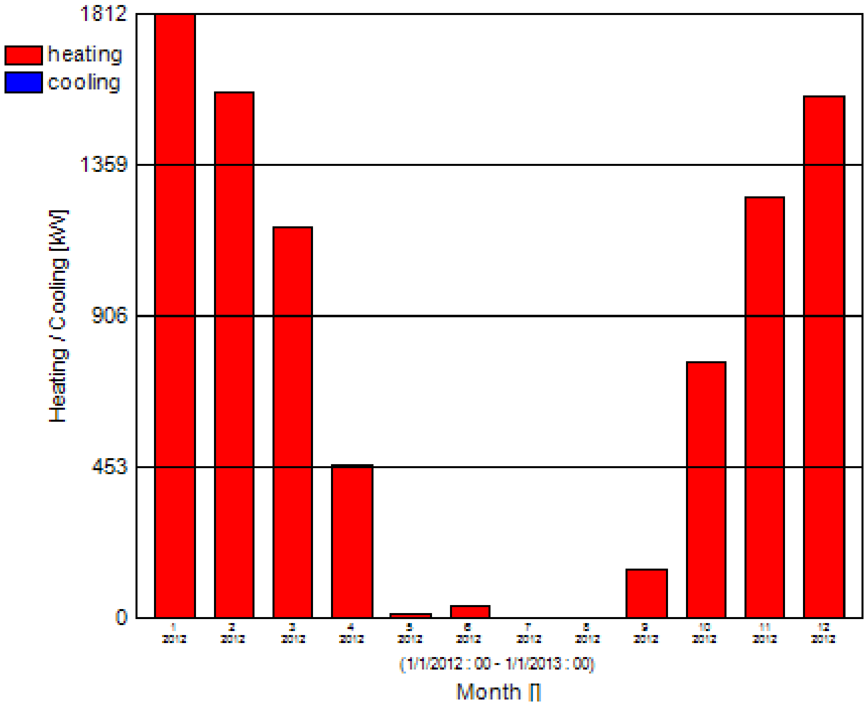


Figure 11 : Monthly heating demand for whole year

Figure 11 shows monthly heating and cooling requirement. As it can be already seen in the data state and results table (Figure 8) total heating requirement for whole year is 8775 KWh i.e. 54.84 KWh/m^2.

Film and EXPORT:

For an individual component, a film which contains the profiles of all time steps can also be filmed. WUFI automatically records the initial and final states as profiles. You can specify additional points in time for which you want to see profiles. If you select "Retain calculation results" the results and films concerning this component are saved after calculation.

This film shows the variation in temperature along the different component on its cross section. Water content and relative humidity along the cross section is also recorded on this film. Figure 12 shows a temperature, variation along the wall section, at a point during simulation. Water content and relative humidity profile does not show as the simulation is done to calculate thermal entities only.

It is also possible to export the needed results as ASCII to Excel or file. All calculated courses and graph curves can be selected. There is also the possibility to choose the time interval.

Figure 13 and 14 shown here are the results of exporting indoor and outdoor temperature from the list of entities calculated during WUFI simulation and using the same export result to plot a day profile of indoor and outdoor temperature in different time of the year.

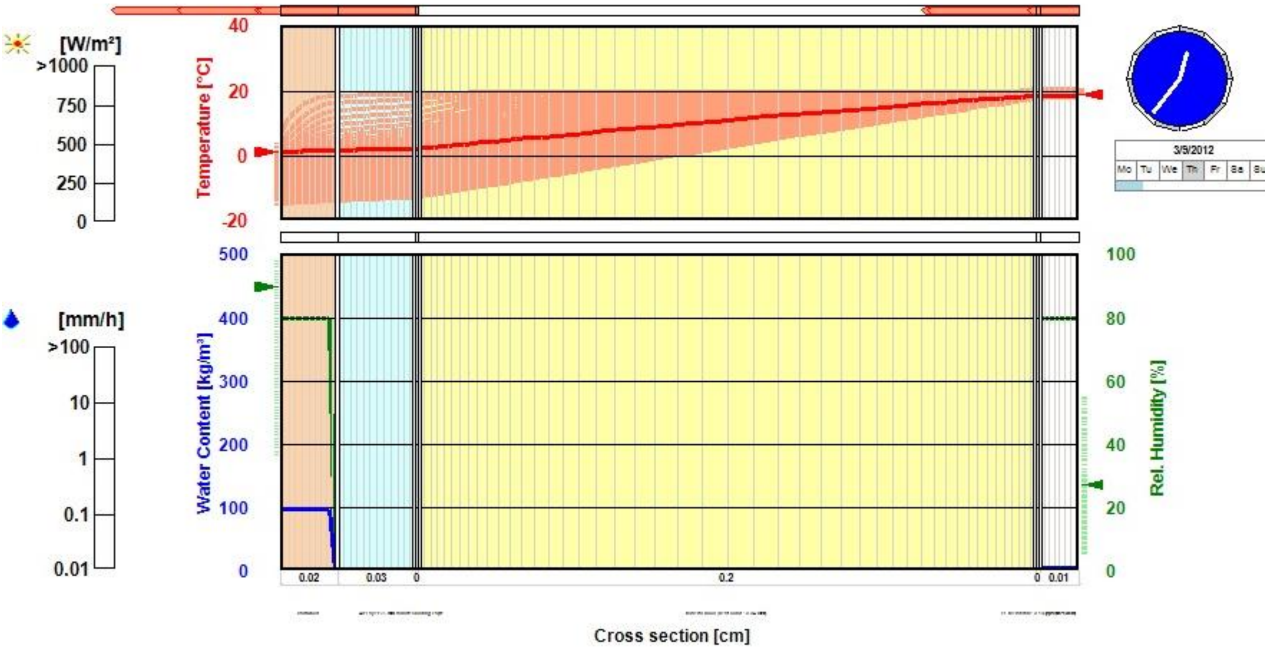


Figure 12: Wall component during simulation.

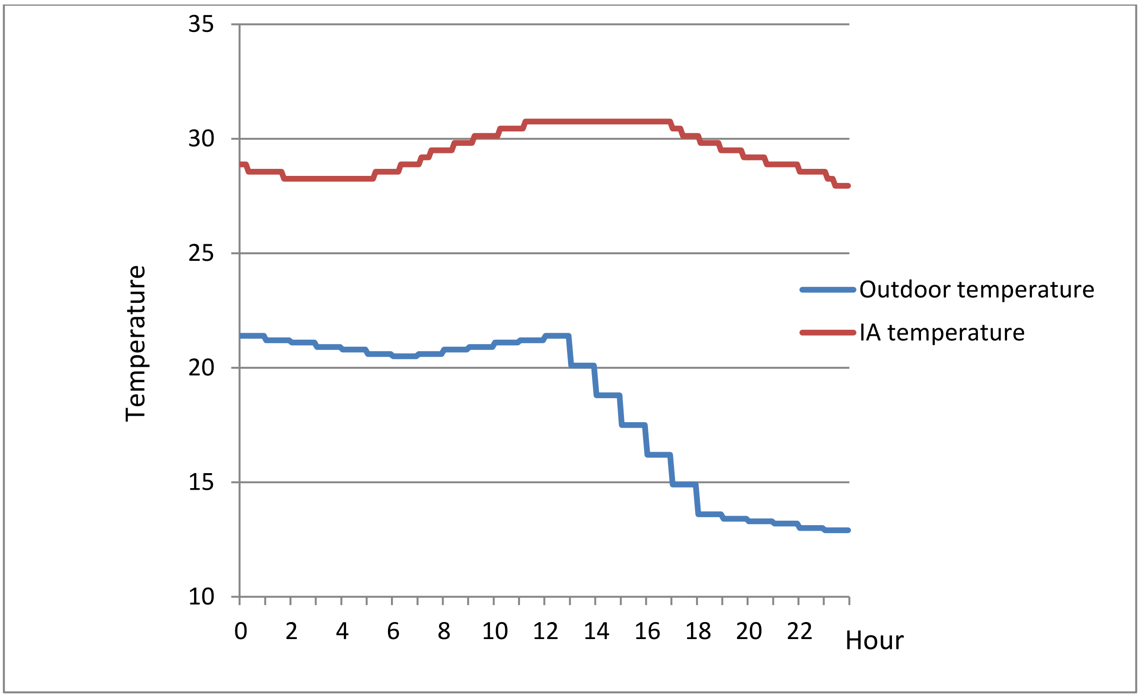


Figure 13 : one day profile of indoor and outdoor temperature for 5th July

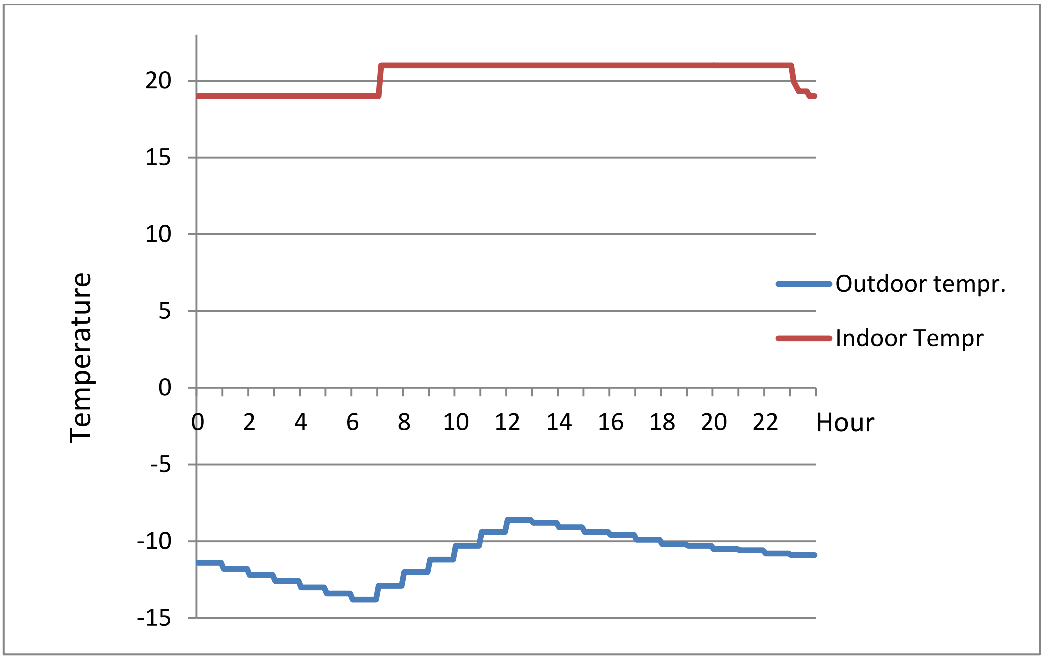


Figure 14 : one day profile of indoor and outdoor temperature for 26th Feb

The result of simulation shows that the indoor temperature of the model goes up to 42°C during summer. The graph of indoor temperature (fig 13) also shows that the indoor air temperature exceeds 30° C on 5th of July only. But as we already know the comfort temperature range for indoor air on summer is 23 °C (73 °F) to26 °C (79 °F)(ASHRAE standard).

The IA temperature is quite high during summer. This IA temperature can be controlled to some extent by applying solar shading to the windows. The explained model is further simulated with shading devices on the windows to see the difference in IA temperature.

2.4.2. Base Case A_x with Shading on window

The above base case A is again taken on WUFI Plus. And this time the windows in Model are provided with shading devices for the summer protection of indoor. The windows on East, West and South are considered to have shading device during summer time to avoid excess heat gain on the indoor.

The solar shading on the window has following parameters.

Table 15: solar Shading Parameters

A reduction factor of the solar radiation (b-value)	.08
Thermal resistance supplement	0
Operation mode	Reduce Overheating/Cooling

Reduce Overheating/Cooling mode of operation implements that the device is used to reduce overheating and cooling of the building beyond specified values. (These values are entered in the Design Conditions)

The results of simulation while applying the shading on window mainly effect maximum IA temperature that can be noted on the table below.

Table 16: Result of Simulation with cooling system

Heating demand	8775 kWh (54.84 kWh/m2)
Cooling demand	No cooling
Maximum indoor temperature	40.8 °C
Minimum indoor temperature	19 °C

Further the energy demand and IA temperature for the year or certain time of can be seen as a graphical representation for this case.

The results show, introducing solar shading devices on the window has already reduced the maximum IA temperature by 2°C. Further the energy demand and IA temperature for the whole year or certain time of can be seen as a graphical representation for this case.

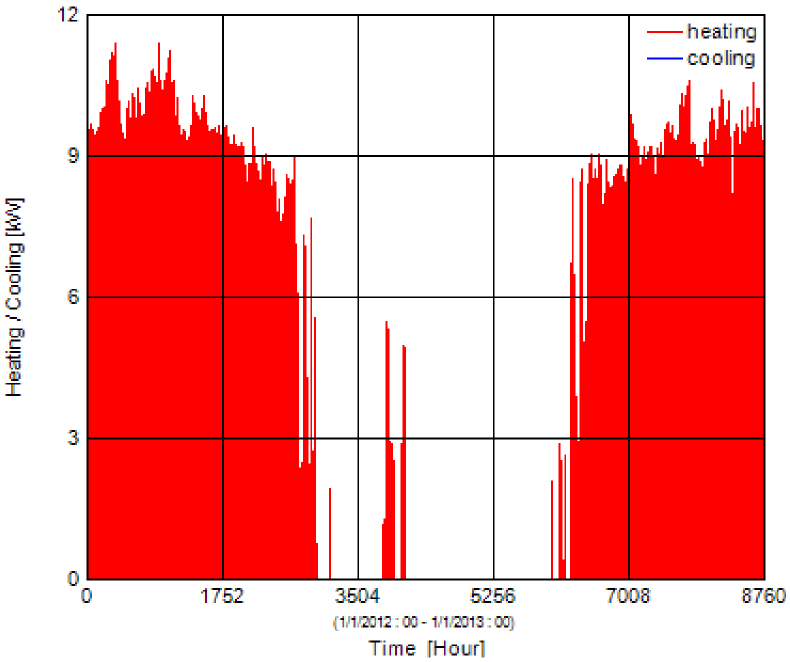


Figure 15: Heating energy

Similarly, the IA temperature distribution for a summer day and a winter day can be plotted from the data exported from WUFI.

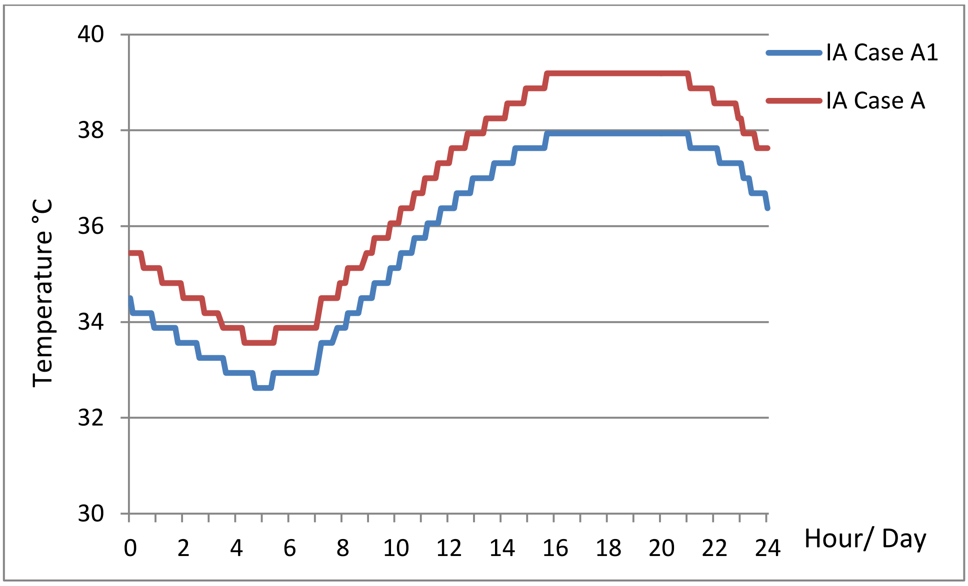


Figure 16 : IA temperature measure in every 0.1 hour for 5th July (Summer)

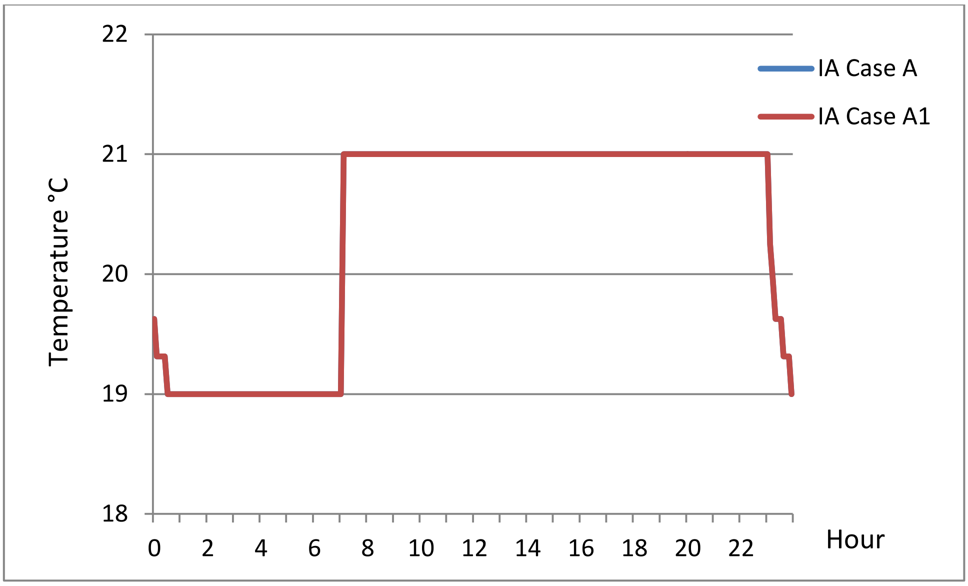


Figure 17 : IA temperature for Feb. 2 (winter)

The IA temperature during summer reduces in case with solar shading A_x as the shading applied to the windows reduces solar transmittance into indoor. Nevertheless the IA in winter is same as in case A, as the heating system applied to the model maintains the minimum temperature required.

2.4.3 Base Case B

Simulation with New window Condition:

The SHGC factor of the window and the shading devices are other factors effecting the solar transmission into the indoor environment. The indoor air temperature largely depends on the amount of solar heat that enters the building through window and the solar transmission into the building depends on the SHGC value of the window and the solar shading condition.

Hence following simulation helps to point the effect of window parameters in the IA temperature and thus the energy demand of the building.

The SHGC value for all the windows are lowered to 0.3, solar shading is introduced to the windows on South and west, and a cooling system is introduced to the model for new simulation. Design condition and result of this simulation are further discussed.

Design conditions for case B

- Climate data for Oslo
- Minimum temperature at working hours 21° C
- Minimum temperature outside working hour 19° C
- Maximum temperature 27° C
- Shading devices on South and West window
- General heating system and mechanical ventilation system with 80% heat efficiency

Table 17: New window parameters

U- value (W/m^2K)	1.2
Frame factor [-]	0.7
SHGC Hemispherical [-]	0.3
Emissivity of external surface [-]	0.85
Solar shading	south and west window

Table 18: Parameters for solar Shading

A reduction factor of the solar radiation (b-value)	.08
Thermal resistance supplement [m^2K/W]	0
Operation mode	Reduce Overheating/Cooling

Reduce Overheating/Cooling mode of operation implements that the device is used to reduce overheating and cooling of the building beyond specified values. (These values are entered in the Design Conditions)

The values of heating and cooling demand and IA temperatures from WUFI simulation are as shown on table below:

Results of Simulation for case B

Table 19: Results of Simulation

Heating demand	9694.1 kWh (60.5 kWh/m2)
Cooling demand	-137 kWh
Maximum indoor temperature	27°C
Minimum indoor temperature	19°C

the results on the table above can also be presented in a graphical manner. The graph here shows IA temperature and heating demand plotted for the whole year. The graphs taken from WUFI Plus results.

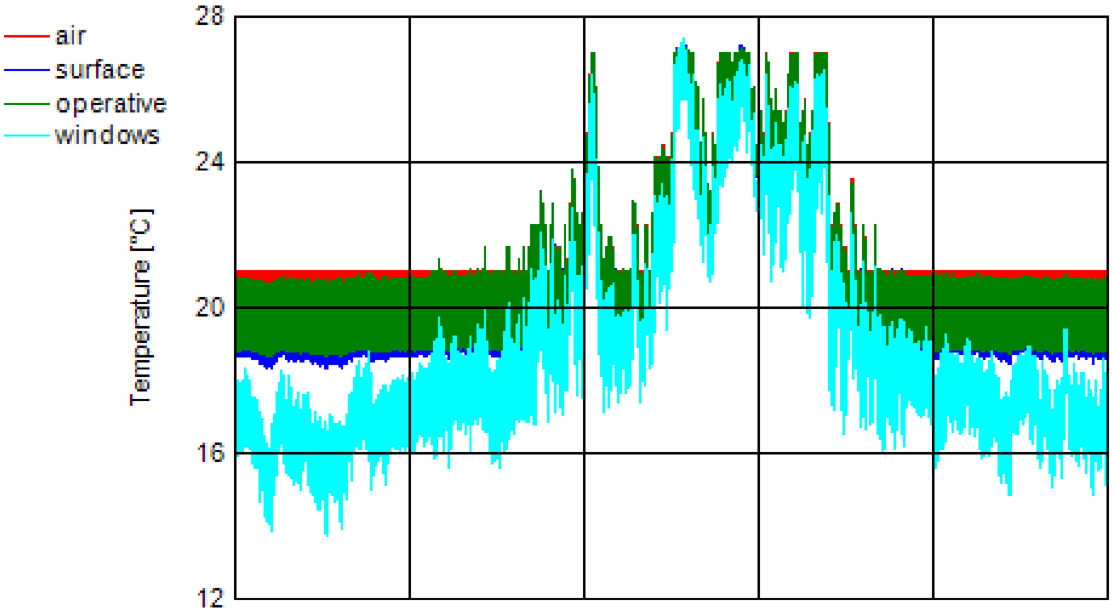


Figure 18 : Indoor temperature for new condition

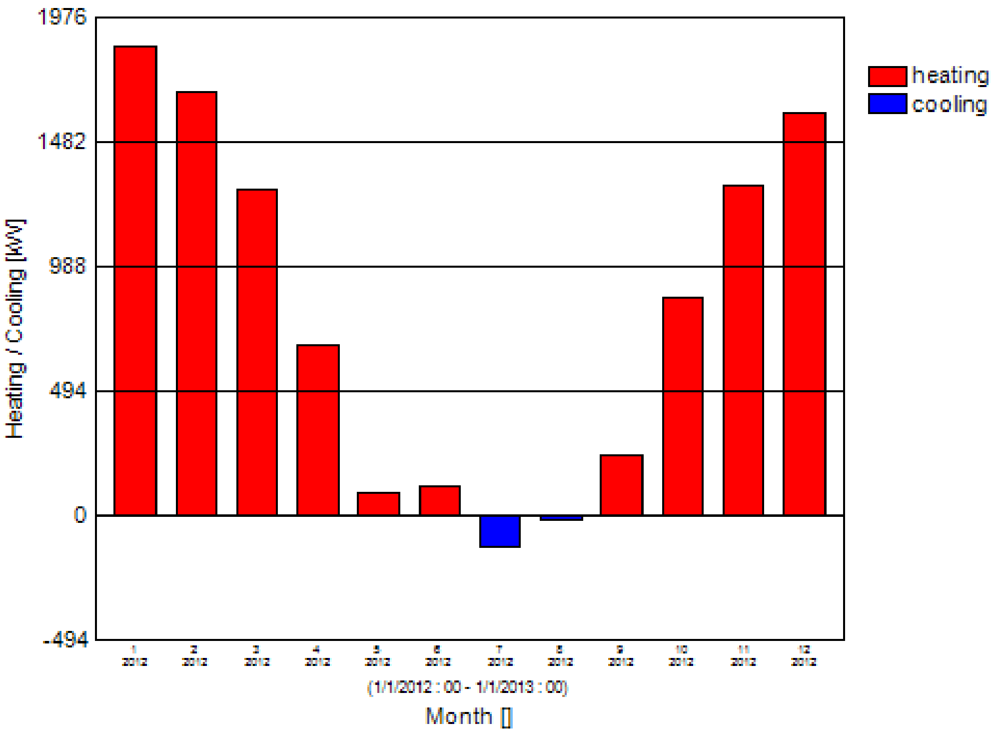


Figure 19 : Monthly heating and cooling demand

Graph shows the heating and cooling energy required along the months. Some cooling is required on July and very little cooling on August to keep the room temperature within the comfortable condition. Heating is required on all other period of year. Heating demand is highest during December, January and February.

A day profile of temperature is then plotted to compare this new results with earlier simulation without cooling and different window parameters.

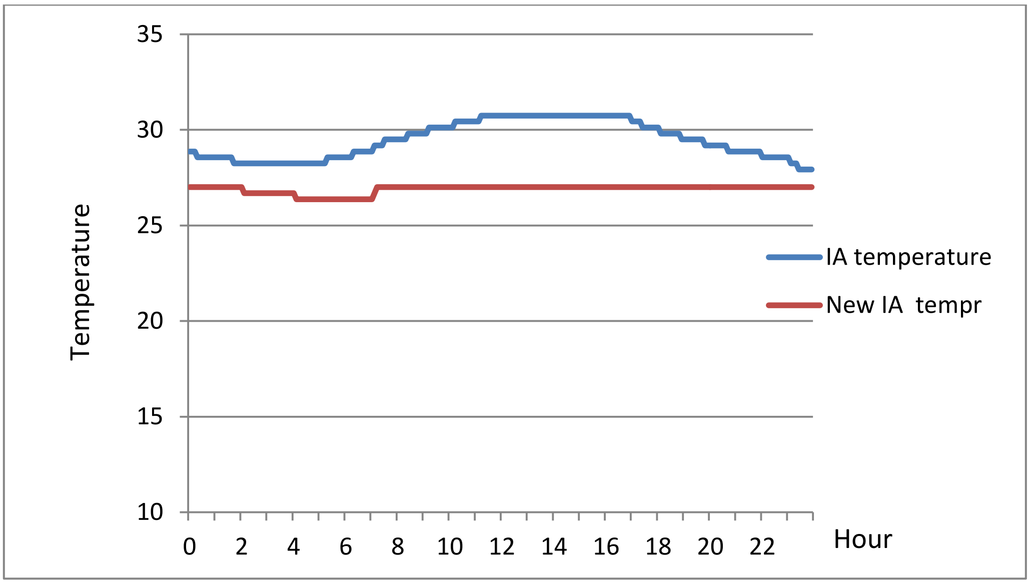


Figure 20 : IA comparison on 25th July

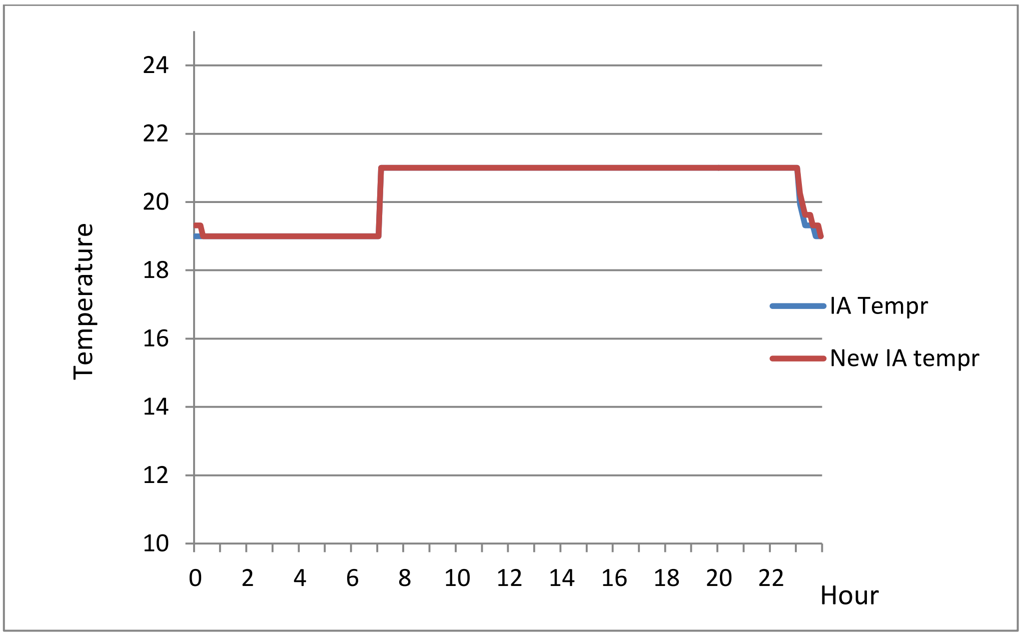


Figure 21 : IA comparison on 26th February

Figure 20 and 21 shows a day profile of indoor air temperature for a hot summer day (July 5th) and a cold winter day (Feb. 26th). Plotted data shows the comparison of indoor air temperature for two different design condition used on simulation. Blue line plotted on the graph is the indoor air temperature of the model when no cooling is applied and another line on the graph, the red line represents variation in temperature when the window parameters are changed as indicated on table 17 and a cooling system is introduced to the simulation. Comparison of these graphs shows that the indoor room temperature is lowered much to achieve higher comfortable condition but on the other hand, the energy demand is increased to some level as the cooling is also desirable.

2.5. Comparison of Results

The results of simulation from WUFI Plus were compared to the simulation of same model with SIMIEN. As already mentioned earlier in the description of model, the base case taken for simulation here is a SINTEF dwelling box comprising of the standards and measures for a residential unit. This SINNTEF box has been simulated with SIMIEN for the calculation of energy use and the indoor condition. The results obtained from the WUFI Plus were compared to the SIMIEN results before doing further analysis for the standardization and verification of the explained case and the results.

The result compared here is for the case A_X with shading on windows but no cooling applied. As it implies a design of typical Norwegian residence that is a base for the simulation on SIMIEN.

Table 20: comparison of SIMIEN and WUFI results

	WUFI Plus result	SIMIEN result
Energy demand (kWh)	8775	9247
Energy demand (kWh/m^2)	54.84	57.79
Max. IA temperature (°C)	40 °C	37.3 °C
Min. IA temperature (°C)	19 °C	19 °C

The above table of results shows the results of energy demand and IA temperatures: for WUFI Plus and SIMIEN simulation. The comparison of results shows that the values of energy demand and IA temperatures are comparable. Certain differences in the result here is due to different software used for simulation. The priorities of software during simulation are varied, for instance, the simulation done here on WUFI takes only thermal parameters in consideration while SIMIEN calculates for both thermal and moisture factor.

A brief report of results of SIMIEN has been attached to ANNEX- II at the end of the report.

CHAPTER 3

3.0. Simulation and Results

In this chapter, the Base cases are simulated with PCM applied on different components of the model. All three cases are simulated separately and the results of different cases are compared on later chapter.

3.1 Simulation of model with PCM on Wall

3.1.1. Simulation of Base case A

The first base case explained on the earlier chapter has been simulated again with the PCM applied to its different components, the variation in results while applying PCM on different situation is explained here.

Case A.1: Exposed PCM on Wall

A new layer of PCM is added to the inner surface of the wall on base case A and the simulation is done. All the other conditions of design, including the heating and ventilation and the inner loads are kept same to make the comparison with the earlier base case that we discussed in Chapter 2. The design and window and all the other building components and there U-values are same as that for earlier explained case. The new wall assembly for this simulation is as shown on the table below.

Table 21: Wall Assembly Case A.1

S.no	Material Layers (From outside to inside)	Density (Kg/m^3)	Heat Capacity J/kg	Thermal conductivity W/mk
1.	Hardwood	650	1500	0.13
2.	Air layer 25mm	1.3	1000	0.155
3.	60 minute Building Paper	280	1500	12
4.	Mineral Wool	60	850	0.04
5.	PE-Membrane 0.15 mm	130	2200	2.2
6.	DuPont Energain, PCM	855.5	6000	0.18

The wall assemblies still possess similar thermal properties as the wall on Base case. U-value of the wall is 0.18 W/m^{2}K and its thermal resistance is 5.37m^{2}K/W.

Results of Simulation:

Among all the other values calculated by the simulation, the report compares the heating and cooling demand of the model and also looks into the difference in the IA temperature of the model when PCM has been applied to the walls.

Table 22: Results of Simulation case A.1

Heating Demand (kWh)	8547.2
Cooling Demand (kWh)	- (No cooling applied)
Maximum temperature (°C)	42
Minimum temperature (°C)	19

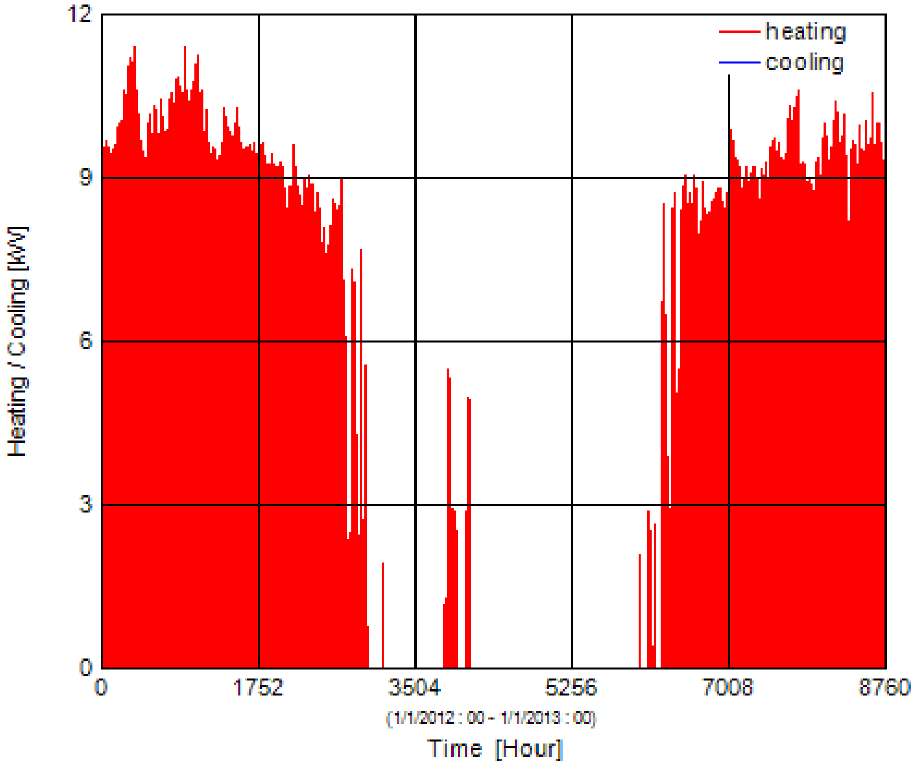


Figure 22: Energy distribution (kW) throughout the year- Case A.1

Above figure is the distribution of heating energy demand during the course of whole year. Energy required here is heating energy, the figure does not show cooling, as no cooling system has been applied. Heating required is maximum in early days of the year representing extreme winter and none heating demand is required during summer period of year.

The comparison of indoor air temperature can be seen on the graph below:

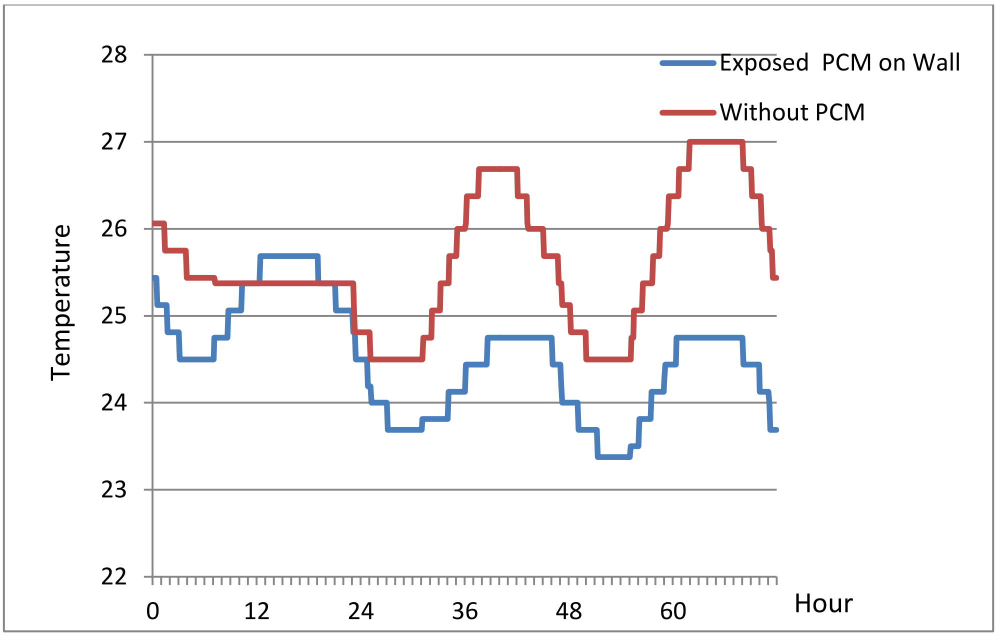


Figure 23: IA temperature comparison Base case A and case A.1 in summer

The above figure is a graphical representation of IA temperature of the model for three simultaneous days on 3rd, 4th and 5th of June i.e. for summer. A similar graph plotted for winter shows no variation in IA temperature, as the heating system applied maintains the room temperature between 19-21°C for all the cases.

The graph shows the temperature measured on per unit time at the time interval of 0.1 hour. The values on X- axis are temperature measured in °C and on Y axis, time in hour. Two lines on the graph are representing temperature measures for the condition without PCM (Base case A) and with exposed PCM (Case A_x) on wall.

Red line on the graph is the IA temperature measure without PCM whereas the blue line is temperature of Indoor air with exposed PCM on wall. Comparing these two lines on the graph, when the temperature of indoor air starts to increase as per the start of day 2, hour 24 onwards on the graph, the temperature of indoor goes rapidly up (up to 26.7 °C) in the case without PCM but when the PCM is applied, the temperature rises slowly as the PCM absorbs the heat from external till it reaches its melting point Hence the IA temperature changes slower. Similarly when the temperature starts to decline, the IA temperature rapidly goes down in case without PCM but in case with PCM, it keeps the IA temperature constant for a longer period of time. Hence the application of PCM results in less fluctuation of IA temperature in a day profile. Similarly, this process repeats for each day.

Case A.2: PCM on Wall with Gypsum layer

To analyze the behavior of PCM the above case was simulated on WUFI again with a gypsum layer added the wall assembly. All the other conditions are same.

Table 23: Wall Assembly- Case A.2

S.no	Material Layers (From outside to inside)	Density (Kg/m3)	Heat Capacity J/kg	Thermal conductivity W/mk
1.	Hardwood	650	1500	0.13
2.	Air layer 25mm	1.3	1000	0.155
3.	60 minute Building Paper	280	1500	12
4.	Mineral Wool	60	850	0.04
5.	PE-Membrane 0.15 mm	130	2200	2.2
6.	DuPont Energain, PCM	855.5	6000	0.18
7.	Gypsum Board	850	850	0.2

Result of Simulation

The results of simulation were then compared to the heating demand and IA temperature of the earlier case.

Table 24: Results of Simulation Case A.2

Heating Demand (kWh)	8490.4
Cooling Demand (kWh)	- (No cooling applied)
Max. IA temperature (°C)	41.1
Min. IA temperature (°C)	19

The values of energy demand and maximum IA temperature are affected by the changes applied to the simulation. The table of results shows these values and the following figure is a difference in IA temperature in daily profile.

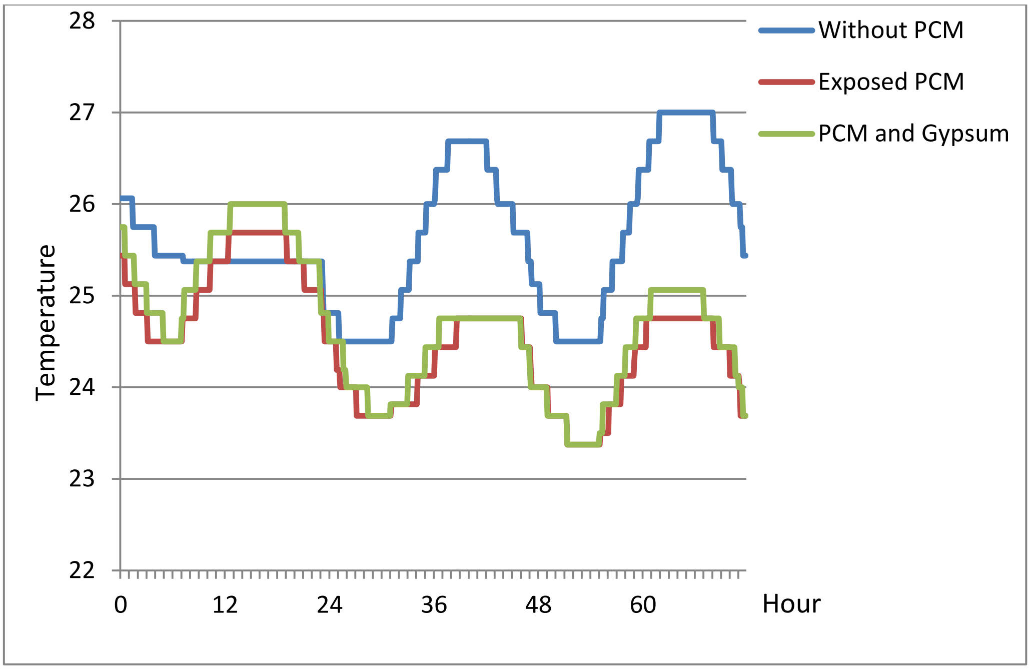


Figure 24: IA temperature with PCM on wall: Case A, A.1 and A.2

Graph shows the IA temperature comparison for three different cases of simulation done without PCM, with exposed PCM and with PCM and gypsum applied on the inner surface of wall.

Three different colored lines on the above graph 24 shows the three different cases as indicated. As already explained on the earlier case, Indoor air temperature fluctuation is quite high when measure without any PCM on the model. But this temperature variation is lesser when PCM is applied. This is due to the characteristic of PCM to absorb the heat until it reaches its melting point and later release this heat to maintain the room temperature.

The application of gypsum layer does not seem to have much effect on the indoor air temperature. As the red and green line on the graph for the condition with exposed PCM and PCM with gypsum layer do not vary much.

3.1.2. Simulation of Base Case A_X

Case A_X.1. Exposed PCM on wall

Table 25: Results of Simulation

Heating Demand (kWh)	8539.6
Cooling Demand (kWh)	- No cooling
Max. IA Temperature (°C)	40.1
Min. IA Temperature (°C)	19

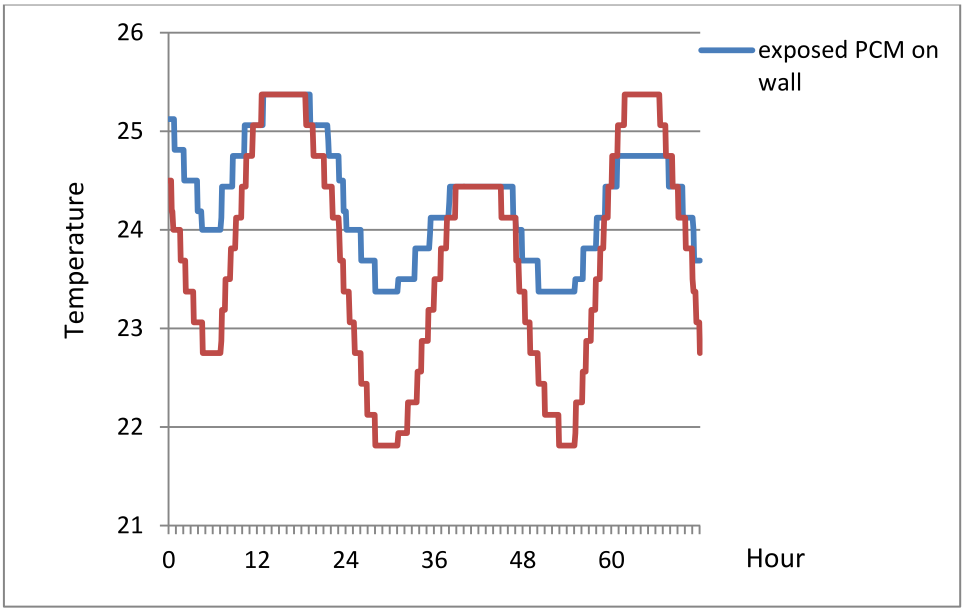


Figure 25 : IA temperature with exposed PCM and no PCM during summer

Case A_X. 2. PCM on wall covered by Gypsum

Table 26: Results of simulation, Case A_x 2

Heating Demand (kWh)	8487.5
Cooling Demand (kWh)	No cooling
Max. IA temperature (°C)	39.8
Min. IA temperature (°C)	19

IA temperature graph

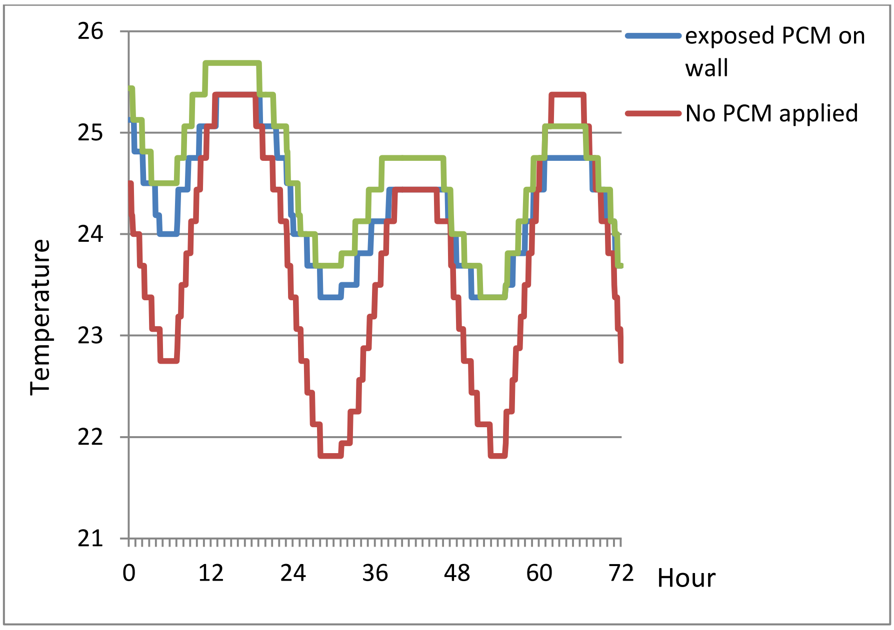


Figure 26: IA temperature with PCM on wall, case A_x.1

3.1.3. Simulation of Base case B

The simulation of model as explained on the earlier chapter was done again by making some changes on the window parameters and changing some design condition to improve the indoor air temperature. Cooling system was introduces to this simulation to control indoor temperature during hot.

Table 26: Results of Simulation Base case B

Heating demand	9694.1 kWh (60.5 kWh/m2)
Cooling demand	-137 kWh
Maximum indoor temperature	27°C
Minimum indoor temperature	19°C

CaseB.1: Exposed PCM on Wall

The base case model with changes on the window parameters and a general cooling system, explained in chapter 2, is used for simulating with PCM applied to the inner surface of wall. The wall assembly for new condition with PCM is as shown on the table below:

Results of Simulation

Following table shows the results of IA temperature and energy demand for the simulation of case B.2.

Table 27: Results of Simulation- Case B.1

Heating Demand (kWh)	9468.5
Cooling Demand (kWh)	-127.5
Max. IA temperature (°C)	27
Min. IA temperature (°C)	19

Further the energy distribution graph for the case and the IA temperature graph are shown on the figures below.

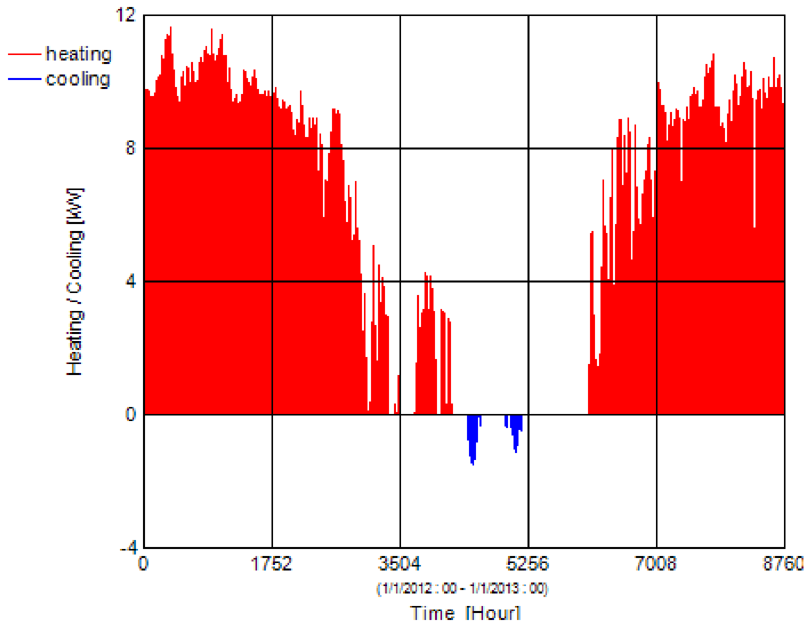


Figure 27: Heating and cooling distribution- Case B.2

Figure 27 is the heating and cooling demand distribution for the whole year. The negative values on the graph, represented by blue lines are the cooling demands required on July and August whereas red bars represent heating demand on the remaining time of year.

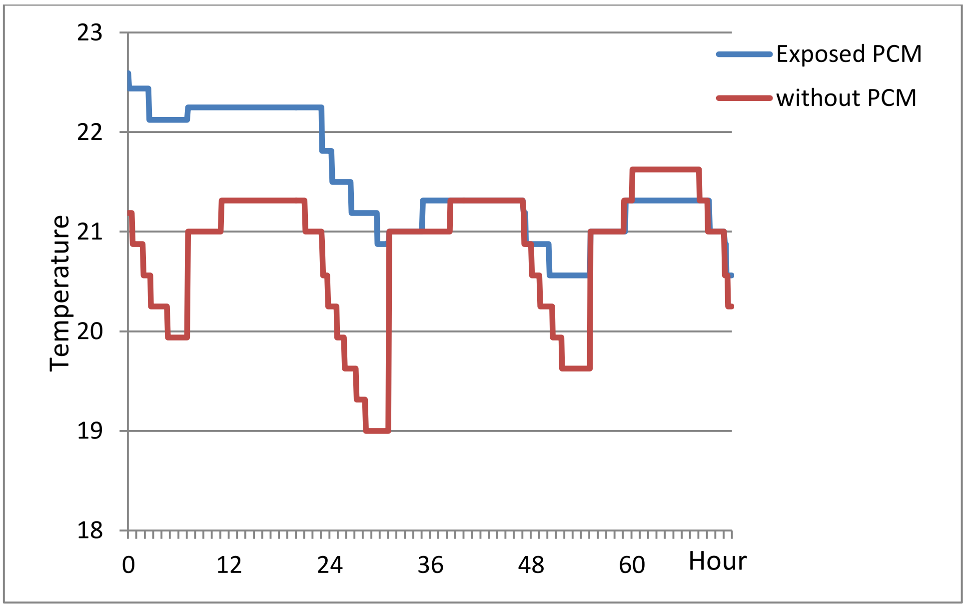


Figure 28: IA temperature with Exposed PCM on wall Case B.1

The above graph (fig 27) illustrates the IA temperature condition measured per .01 hour during the simulation with WUFI Plus. The IA temperature ranges form 20.6-22.6 °C when PCM is applied on the walls of model. And it lies between 19-21.3 °C when PCM is not applied on it. Though the temperature difference is not much larger on these two cases, as we see on the Graph 28, the rise and fall of temperature occurs abruptly in case without

PCM. But when PCM is applied, the change in temperature is gradual keeping it constant for some time.

CaseB.2: PCM on Wall with Gypsum

The above case is again done with a Gypsum layer added in front of PCM. The simulation was done again for thermal calculation. The conditions and results are reported.

Table 28: Wall Assembly

S.no	Material Layers (From outside to inside)	Density Kg/m3	Heat Capacity J/kg	Thermal conductivity W/mk
1.	Hardwood	650	1500	0.13
2.	Air layer 25mm	1.3	1000	0.155
3.	60 minute Building Paper	280	1500	12
4.	Mineral Wool	60	850	0.04
5.	PE-Membrane 0.15 mm	130	2200	2.2
6.	DuPont Energain, PCM	855.5	6000	0.18
7.	Gypsum Board	850	850	0.2

Results of Simulation

Table 29: Results of Simulation Case B.2

Heating demand	9431.7 kWh (58.9 kWh/m^2)
Cooling demand	-124.7 kWh (0.77 kWh/m^2)
Max. IA temperature (°C)	27
Min. IA temperature (°C)	19

Heating demand for the cases B.2 with PCM and gypsum on wall is 9431.7 kWh i.e. 58.9 kWh/m^2. IA temperature remains between 19- 21°C.

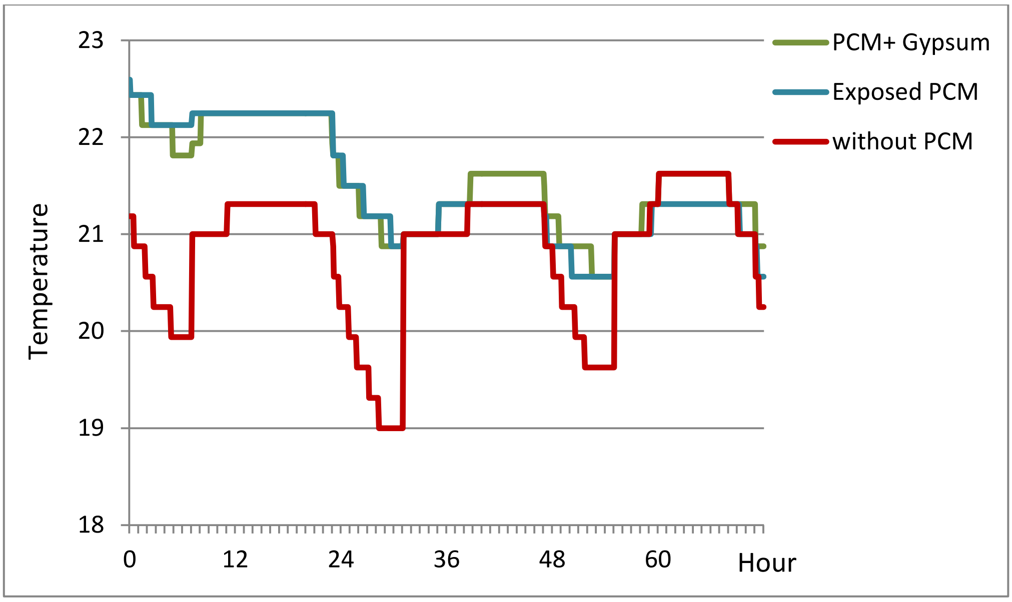


Figure 29: IA temperature with PCM on wall, Case B, B.1 and B.2

Figure 29 is IA temperatures for different cases of base case B with exposed PCM and PCM covered by gypsum applied to the wall.

3.2 Simulation with PCM on Floor

For this simulation, DuPont Energain PCM is applied to all the floor surfaces. Simulation was done in three different steps as in case of wall, first with exposed PCM on floor, and then with PCM and gypsum above it and finally floor finishing was applied at the top.

The floor assembly now consists of material layers as shown on table 30. Later, the results of simulation for both the base cases are shown.

Table 30: Material layers for floor Assembly with PCM

S.no	Material Layers (From top to bottom)	Density (Kg/m3)	Heat Capacity (J/kg)	Thermal conductivity (W/mk)
1.	60 minute Building Paper	280	1500	12
2.	Mineral wool	60	850	0.04
3.	PE- Membrane 0.15 mm	130	2200	2.2
4.	Wood fibre board, hard	800	1700	0.18
5.	DuPont Energain, PCM	855.5	6000	0.18
6.	Gypsum Board	732	1384	0.193
7.	Oak, radial	685	1500	0.13

3.2.1 Simulation of Base case A

Case A.3: Finished floor surface with PCM

The above material layers are applied to define the wall assembly of the new simulation model and the results are compiled. The PCM is applied to the floor on the ground and on first floor.

Table 31: Result of Simulation

Heating Demand (kWh)	8698.1
Cooling Demand	No cooling
Max. IA temperature (°C)	41.7
Min. IA temperature (°C)	19

The IA temperature graph is plotted for a specific time of a year during summer as it was done on the earlier result sections.

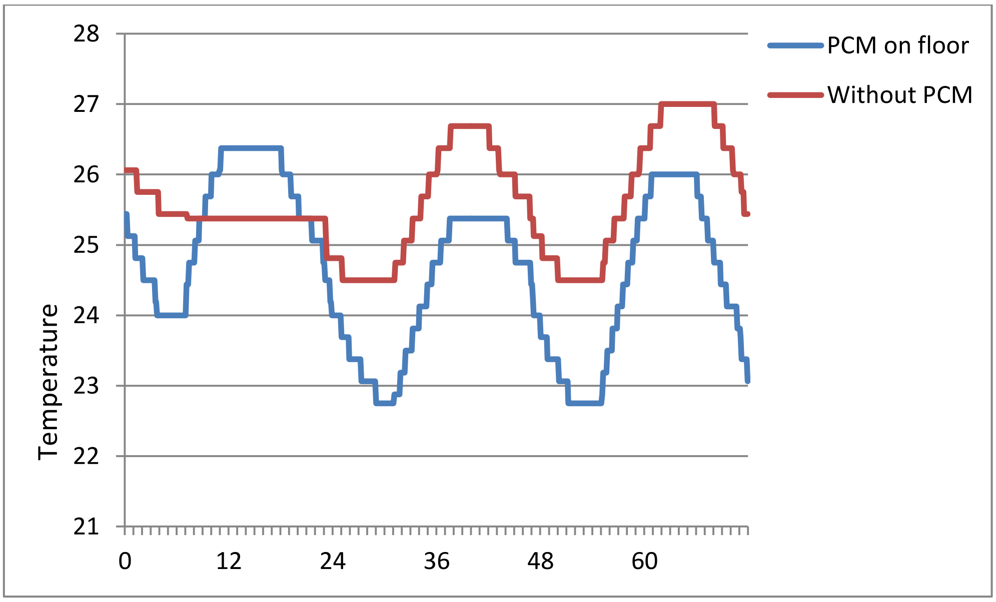


Figure 30: IA temperature with PCM on floor Case- A.3

Figure 30 is a graphical diagram showing IA temperature differences during summer for the case with PCM on floor and without PCM. The temperature measure is taken in every 0.1 hour and the data export from WUFI Plus results are used to plot the graph. Graph shown here is plotted for the IA temperature of the model for 3rd, 4th and 5th of June during summer.

3.2.2 Simulation of Base case A_x

Case A_x. 3. PCM on Finished floor surface

Table 32: Results of Simulation, Case A_x.3

Heating Demand (kWh)	8680.6
Cooling Demand (kWh)	No Cooling
Max. IA temperature (°C)	40.4
Min. IA temperature(°C)	19

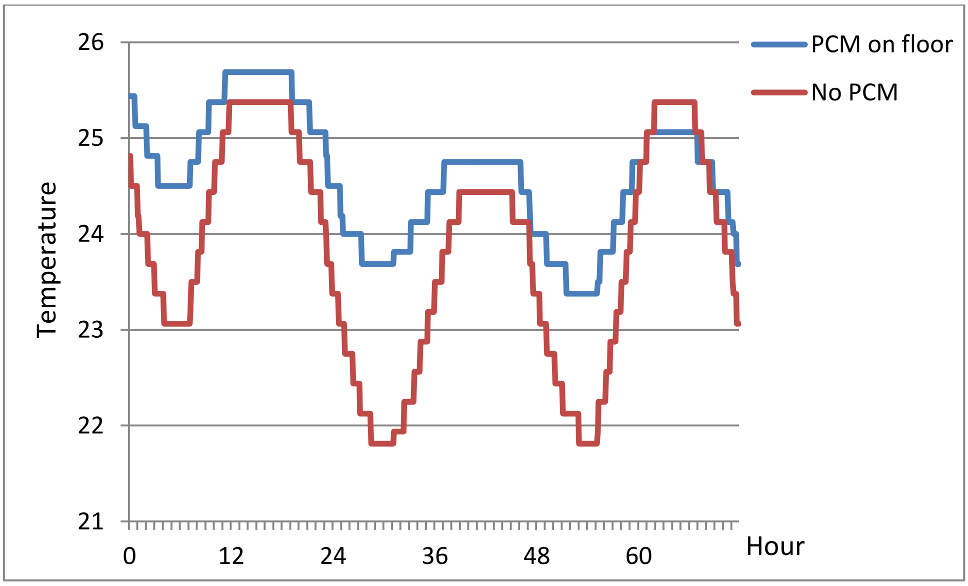


Figure 31: IA temperature with PCM on floor

IA temperature graph here in the above figure shows the temperature condition for the simulation of case A_x when the PCM is applied to the ground floor and upper floor slab.

3.2.3 Simulation of Base case B

Case B.3 Finished floor Surface with PCM, Base case B

The simulation is again done with the PCM on ground floor and first floor for Base case B. The results of simulation are compiled as shown on the table below.

Table 33: Results of Simulation Case B.3

Heating Demand (kWh)	9588.7
Cooling Demand	-125.8
Minimum Indoor air temperature	19
Maximum indoor air temperature	27

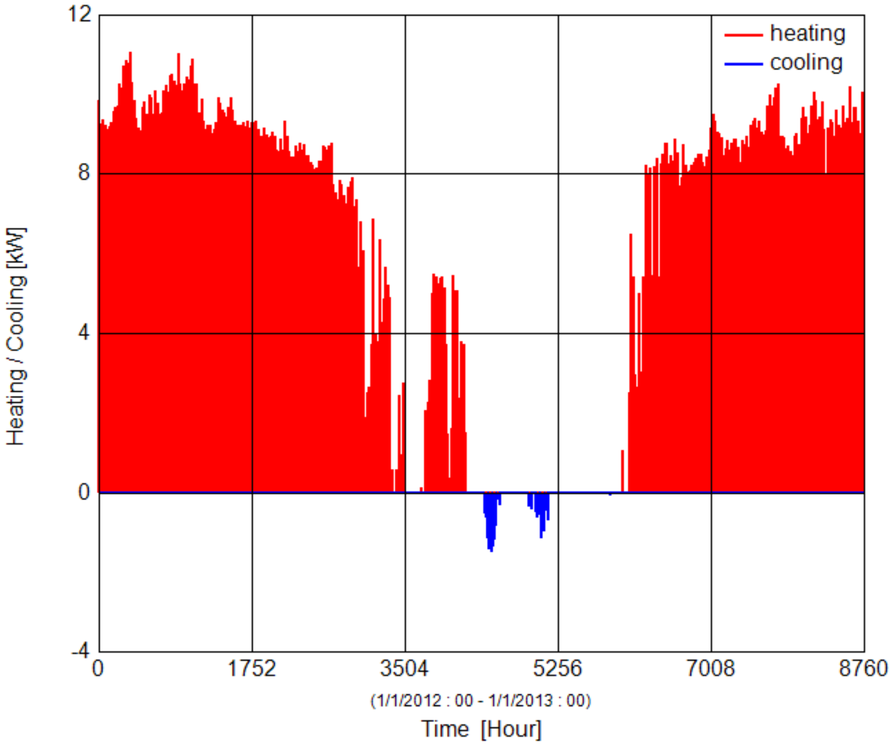


Figure 32: Distribution of energy demand for a whole year

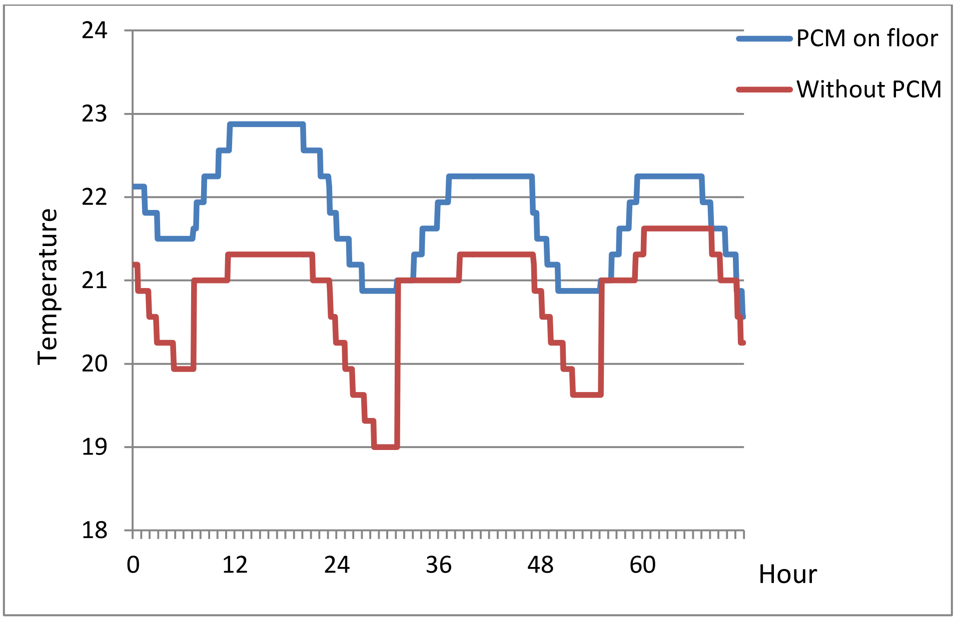


Figure 33: IA temperature, PCM on floor Case A.3

The IA temperature graph again shows the cases with PCM and without PCM applied to the base case B.

3.3 PCM on wall and Floor

All the cases of the model with and without cooling are again simulated with PCM, this time both on floor and the walls. The results of energy demand and IA temperature are shown again.

3.3.1 Simulation of Base case A

The first base case A is the applied for the simulation with PCM on wall and floor. The PCM in both wall and floor are applied with proper finishing. PCM on wall is covered by gypsum board and that on floor if provided with Gypsum and floor finishing layer.

Case A.4: PCM on wall and floor for base case A

Results of Simulation

Table 34: Result of Simulation Case A.4

Heating Demand (kWh)	8458.5
Cooling Demand	No Cooling
Maximum temperature (°C)	40
Min. IA temperature (°C)	19

The numerical results shown on the above table are further shown on the graphical manner with the graphs obtained on the results of WUFI Plus.

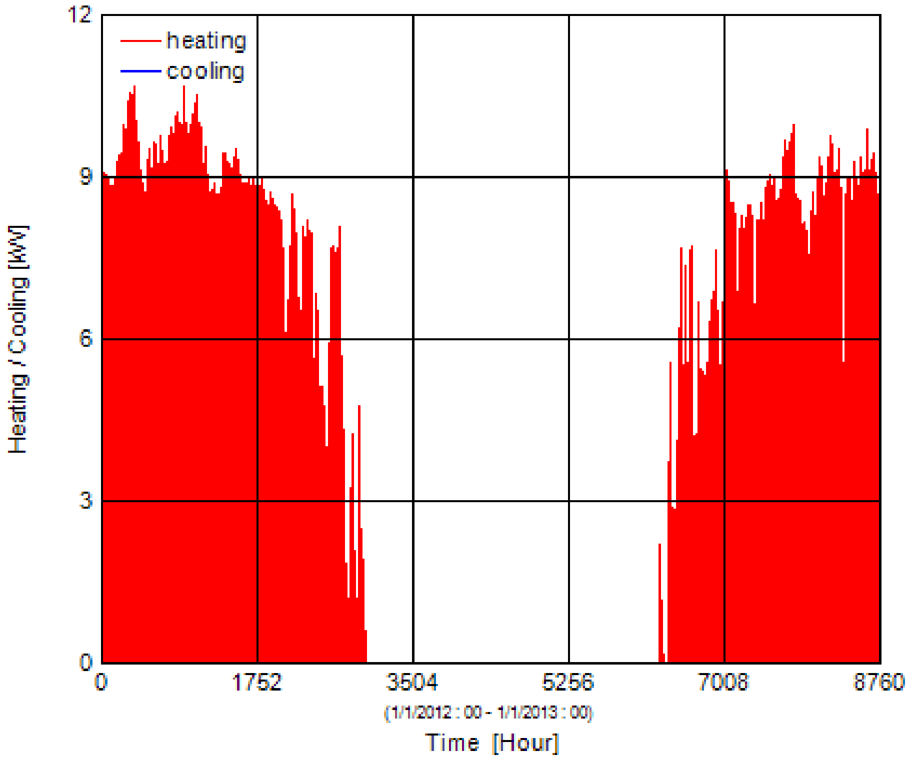


Figure 34: Distribution of heating demand

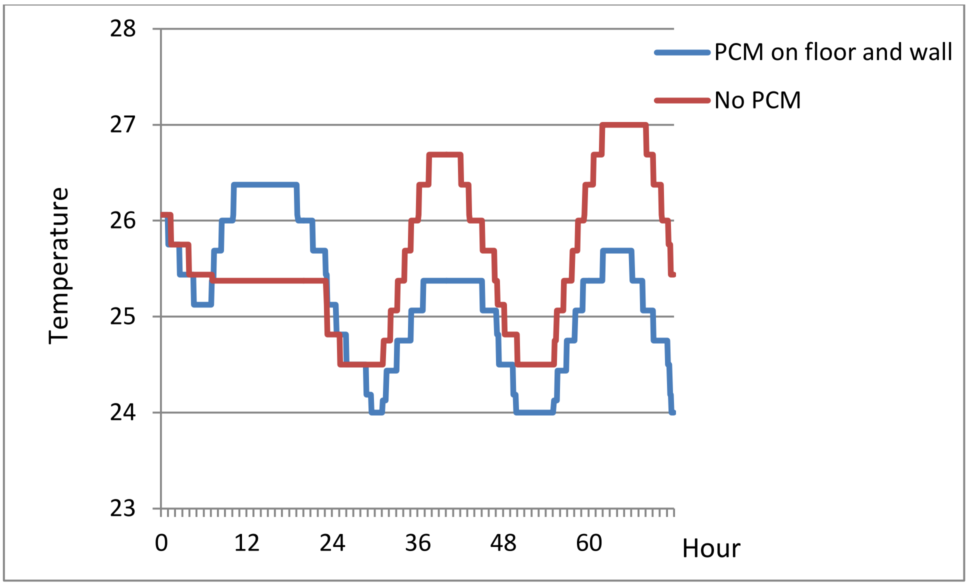


Figure 35: IA temperature of base case A (no PCM) and case A.4 PCM on floor and wall

3.3.2. Simulation of Base case A_x

Case A_x.4: PCM on floor and wall, base case A_x

Table 35: Results of simulation for Case A_x.4

Heating Demand (kWh)	8450
Cooling Demand (kWh)	-
Maximum temperature (°C)	39.2
Min. IA temperature (°C)	19

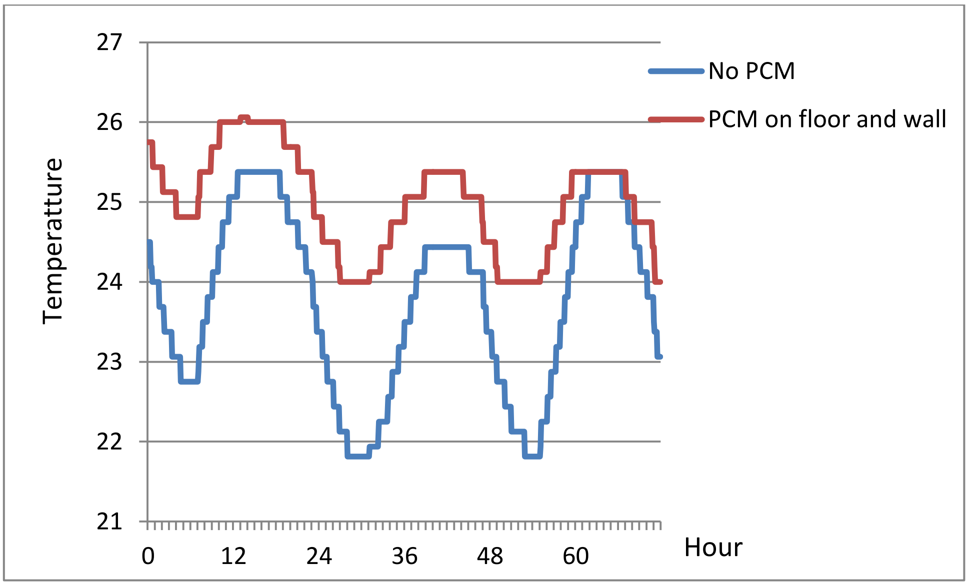


Figure 36: IA temperature with PCM on floor and wall, case A_x

3.3.3. Simulation of Base case B

Similar simulation is again done for another Base case B by applying PCM to the finished floor and wall surface. Results are then shown.

Case B.4: PCM on floor and wall of base case B

Table 36: Result of Simulation with PCM on wall and floor

Heating demand	9345.2 kWh
cooling Demand	-108.3 kWh
Maximum temperature	27 °C
Minimum Temperature	19 °C

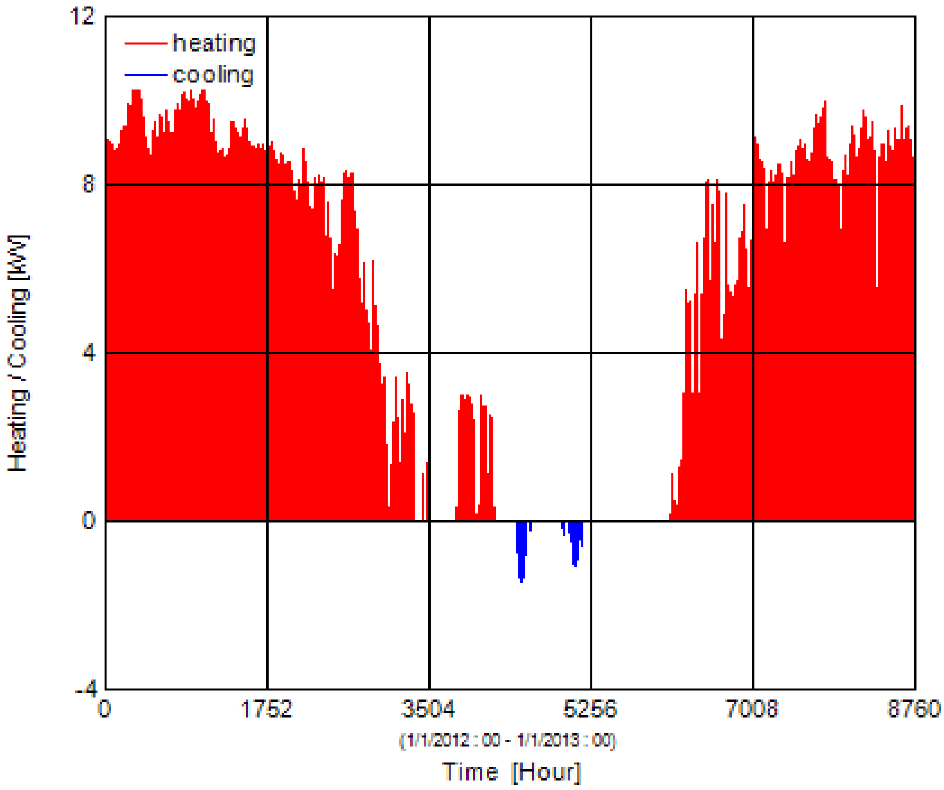


Figure 37: Distribution of energy Demand

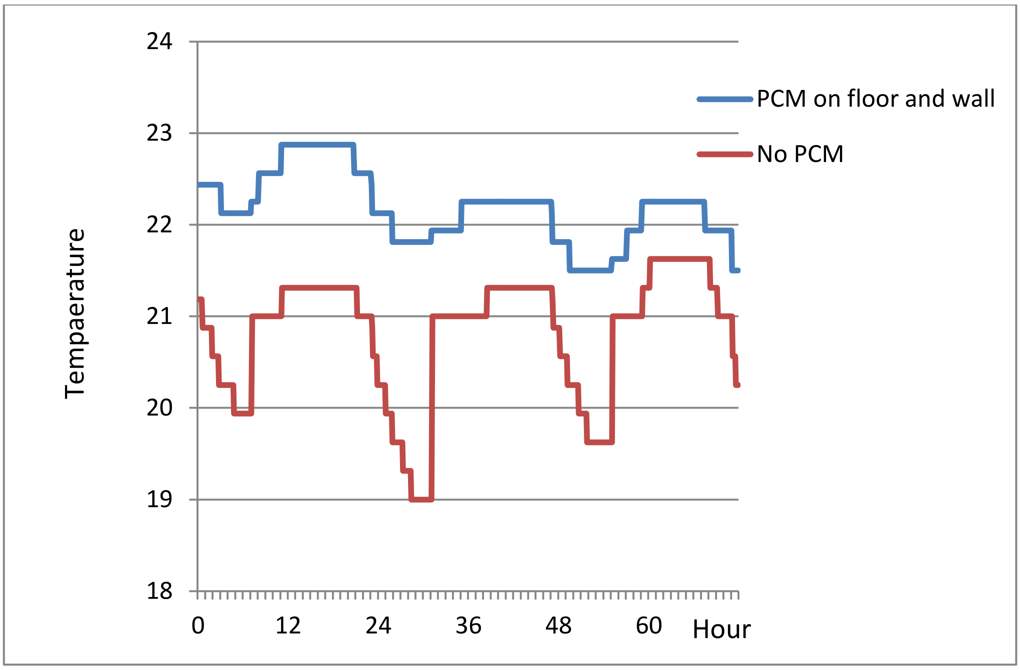


Figure 38: IA temperature for cases B and B.4

Chapter 4

4.0. COMPARISON AND DISCUSSION

This chapter shows various graphs, showing the comparison of IA and energy demand for all the cases that are discussed in the former chapter. A best case for IA temperature condition and considering energy demand is suggested here referring to the result of simulation.

4.1. IA comparison of different Cases

IA temperature for various cases discussed on the earlier chapter 3 are compared and discussed in more detail in this chapter. Different cases of PCM on various components of the model are plotted separately to make the comparison easier. Each graph consists of comparison of all three cases; base case A, A_x and B.

4.1.1 Case with PCM on wall

The first graph here is plotted for different cases with PCM on the wall. Separate graphs are plotted for summer and winter condition to check the variation in temperature indoors in different period of year. For the temperature graph on summer, 5 days in a row is chosen for a specific time of the year, when the indoor temperature tends to go highest.

Figure 39 is the graph representing IA temperature for all the base cases, when PCM is applied to the wall of model.

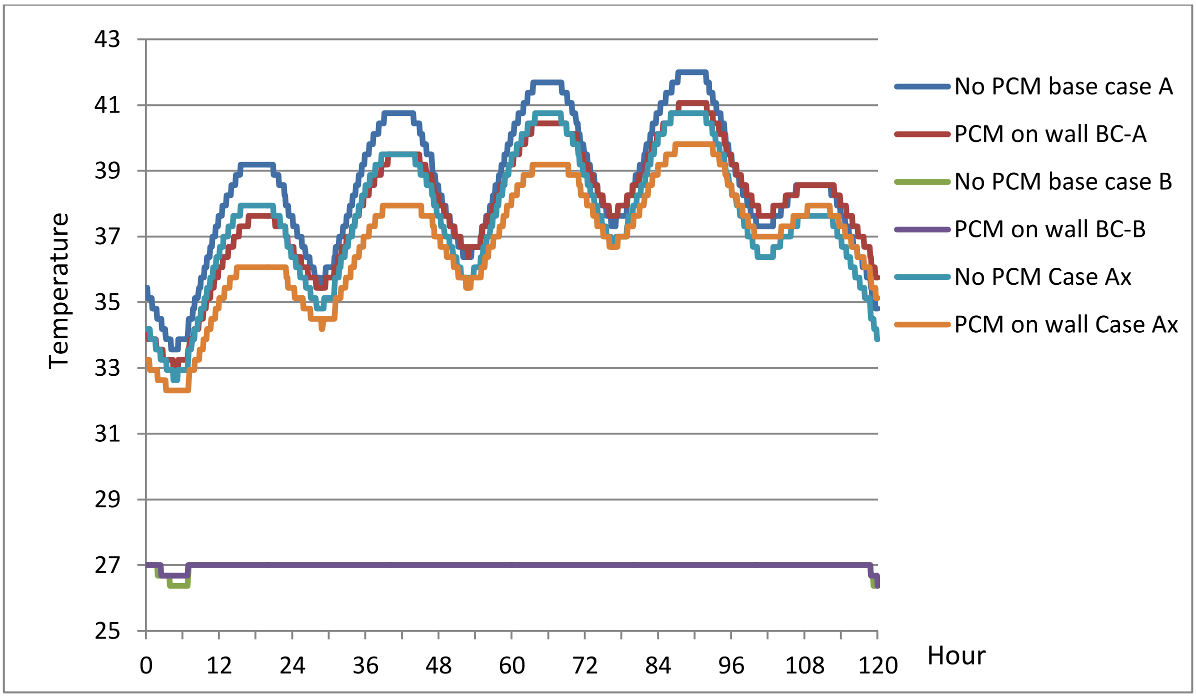


Figure 39: IA comparison of different cases with PCM on wall

The above graph is the IA comparison of all three cases during a hot summer period when the IA temperature tends to reach its maximum value. Graph shows three cases of IA temperature for case A, case A_x and case B. Similarly, it also includes IA temperature for all three cases again with PCM applied to the wall.

For the first base case A, the IA temperature of the model is quite high, up to 41°C at some point. When PCM is applied to this case, the temperature reduces by up to 2°C at the maximum temperature hour of the day. Now if we look into the IA temperature plotted for case A_x the IA temperature is lower than the earlier case, as solar shading has been applied to the windows. The IA temperature still goes lower during maximum temperature hour when PCM is applied.

In case B when cooling is applied to the model, the room temperature is lower as cooling system applied to the model is active to maintain maximum room temperature. But the difference in temperature cannot be marked when PCM is applied as the cooling system functions to maintain the marked room temperatures for both cases with and without PCM.

During winter, when the outdoor temperature tends to go certain degrees below 0°C, the indoor temperature is still maintained to the set temperature by the heating applied to the model. The IA temperature does not show major difference in any case with and without PCM.

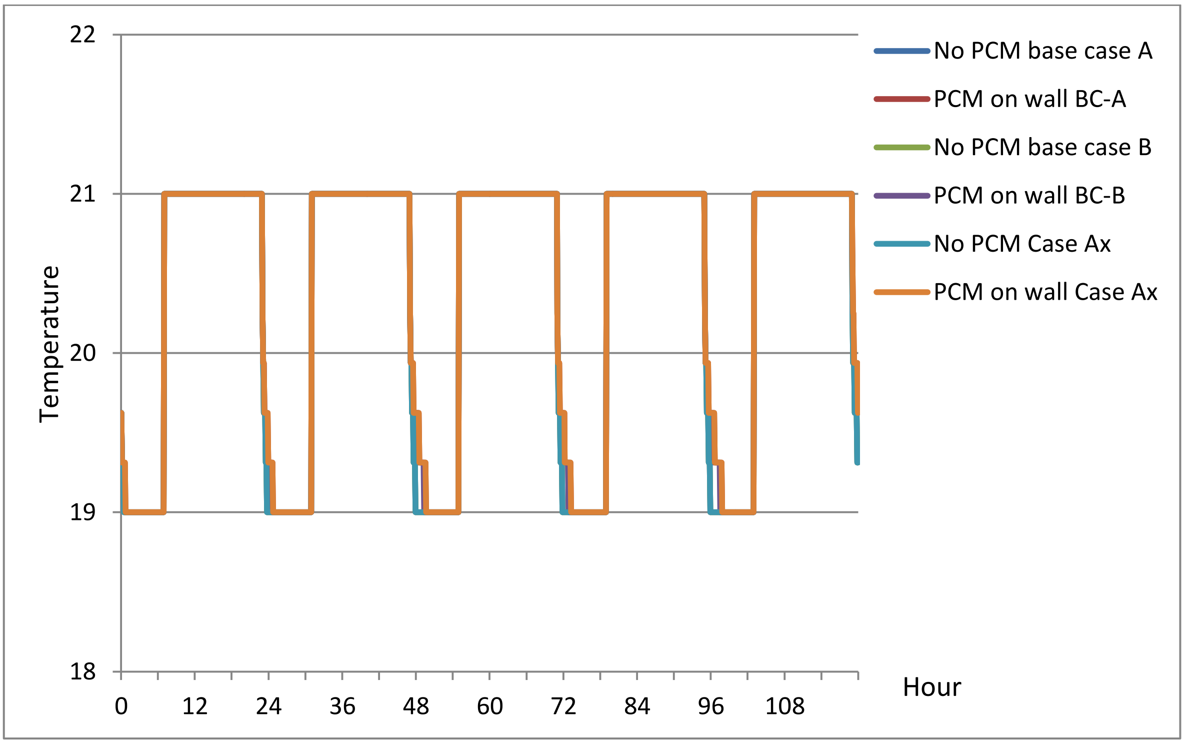


Figure 40 : IA temperature comparison for winter

4.1.2. Case with PCM on Floor

Similarly the IA temperature comparison graph is plotted from the temperature data exported from WUFI Plus for the case with PCM on floor for all the cases. But as since we have noted in the earlier graph (Figure 39) for IA comparison for PCM on wall, there is no temperature variation for case B as the cooling applied maintains temperature between defined ranges. The figure 41 below is the temperature comparison for cases A and A_x on summer when the PCM is applied to the floors of the model.

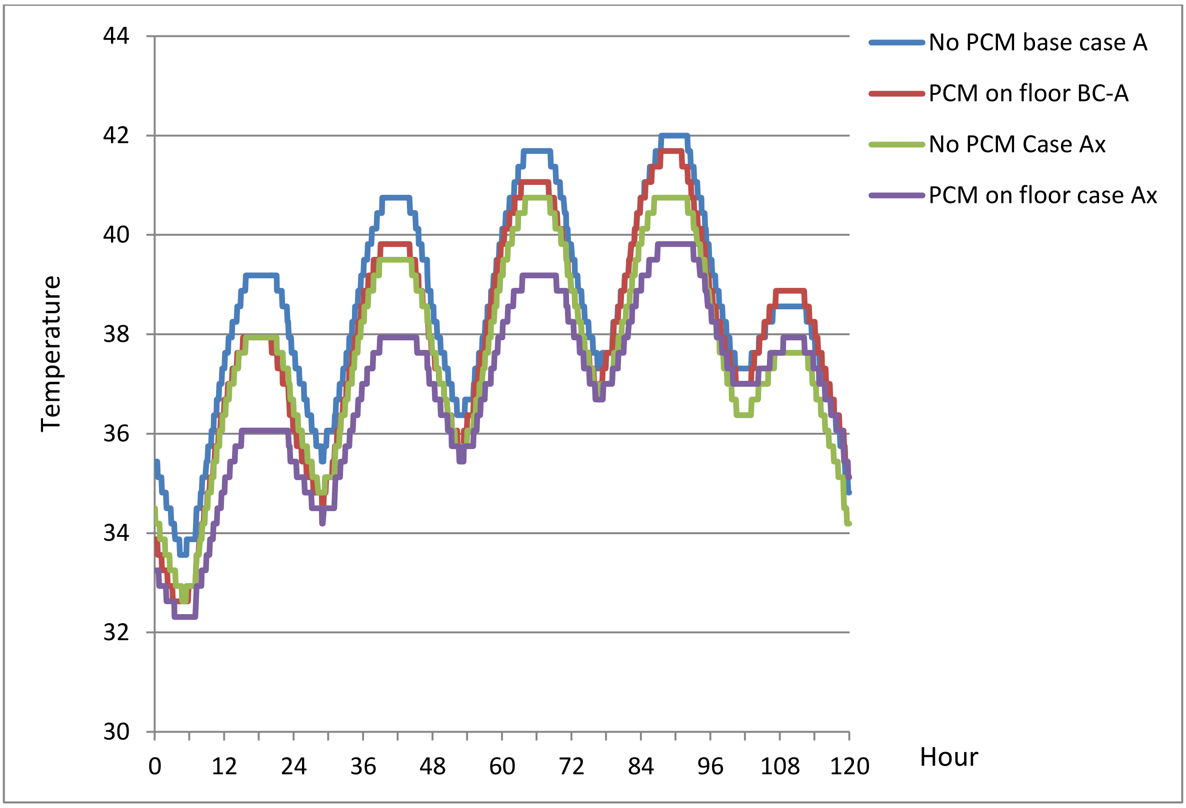


Figure 41 : IA temperature comparison when PCM applied to floor during summer

The variation in temperature is similar as in case of PCM applied to wall. IA temperature lowers up to 2 °C in each case. Above graph shows the IA temperature condition for 5 days in summer. As it can be marked, the maximum temperature on first day reaches up to 39 °C for case A when PCM is not applied but for the same case when PCM is applied, the temperature goes down to 37.8 °C. Similarly for case A_x maximum indoor temperature which is 38 °C lowers to 36 °C when PCM is applied.

The lowering of temperature is due to the property of PCM to absorb the heat during its melting and release the same while solidifying.

4.1.3. Case with PCM on Floor and wall

The following figure is the graph plotted with IA temperature again. This time the graphs are for the cases with PCM applied to the floor and wall. The graph plotted are again for cases A and A_x.

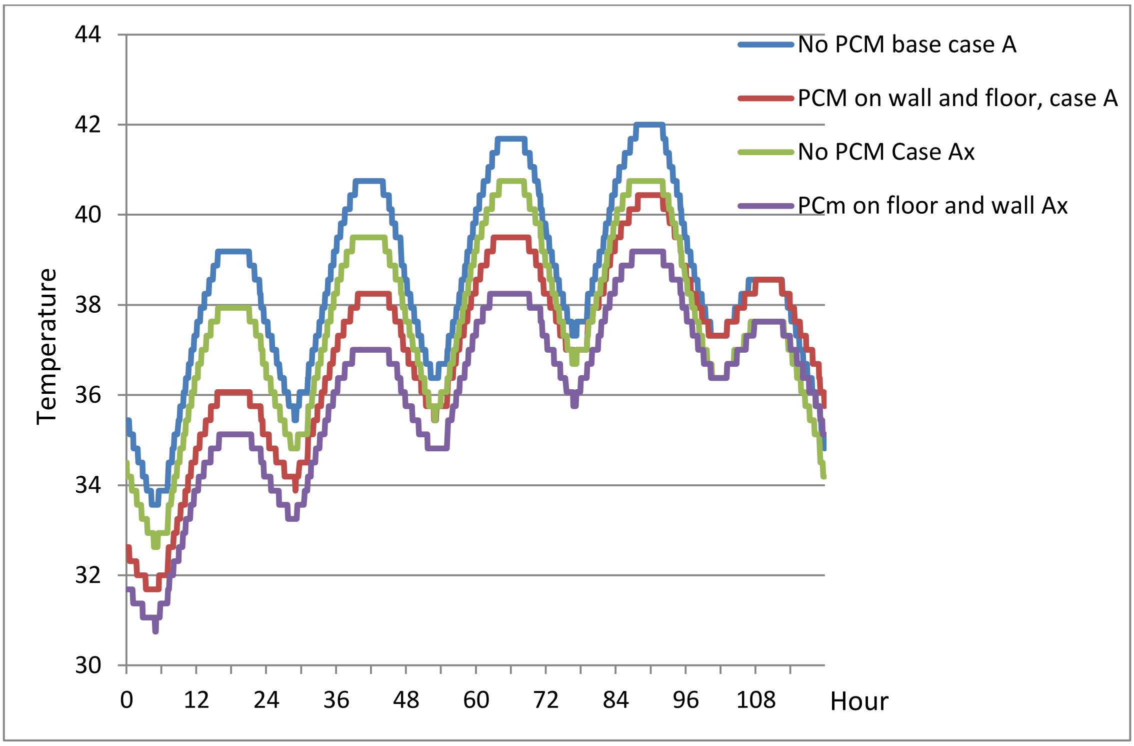


Figure 42 : IA temperature with PCM on Floor and wall during summer

The IA temperature shows difference up to 4°C, indicated on the line graph shown on figure 42 during summer. In winter the temperature variation still lies between 19-21 °C as in earlier cases.

The performance of PCM can be marked more promptly on the temperature difference for both the cases A and A_x as the amount of PCM applied on this case is more than earlier cases.

4.1.4. Discussion of IA temperature

As it can be seen from the comparative graphs, shown on figure 39, 41, 42 the indoor air temperature shows observable difference in summer. The variation in temperature is up to 4 °C during maximum temperature hour. This difference in temperature is seen due to the latent heat storage property of PCM. In the above simulation, we apply DuPont Energain on different components, wall, floor or both.

DuPont Energain panels applied to the model consist of a compound containing a Phase Change Material (PCM) of paraffin wax. At temperatures below 18 °C, the wax remains in a solidified state. Once the temperature inside a room reaches 22°C, due to solar gains and/or external temperatures, the paraffin wax starts to melt. At this stage of phase change, DuPont Energain panel absorbs the heat from a room and slow down the increase in room temperature, providing significant improvement in room comfort. Conversely, as the internal temperature cools, the PCM releases heat back to the room. This way the IA temperature difference is lowered when PCM is applied to a building.

Also the above graph shows comparison of different cases when PCM is applied to different components. The variation in IA temperature can be seen for the same model when PCM is applied to wall of Floor. The case with PCM on both the floor and wall shows the maximum difference in temperature.

Caring that, the simulation takes into account for thermal calculations only, one of the reasons for the variation in IA temperature while applying PCM is the surface area of PCM application. More the area of PCM application, higher is the temperature difference. Below is the table showing the area of PCM application in different cases and the maximum IA temperature of the same case.

Table 37: Differences in areas and Temperature

Case	Area of PCM Surface (m2)	Max. temperature Case- A (°C)	Max. temperature Case- A_x (°C)	Max. temperature Case- B (°C)
No PCM	-	42	40.8	27
PCM on Wall	184.2	41.1	39.8	27
Floor	160	41.7	40.4	27
Wall and Floor	344.2	40	39.2	27

The temperature difference is highest when PCM is applied to both the floor and wall in all the cases. Difference of the maximum IA temperature is up to 2 °C when the area of PCM is maximum.

4.2. Comparison of Heating/ Cooling Demand

The result of energy demands are also shown on the graphical diagrams for the each case separately first and then these graphs are again compared for the discussion of results of energy demand.

The result of energy demands are also shown on the bar diagrams for the each case of PCM on wall, on floor and on floor and wall separately. Then these graphs are compared for the discussion of results of energy demand.

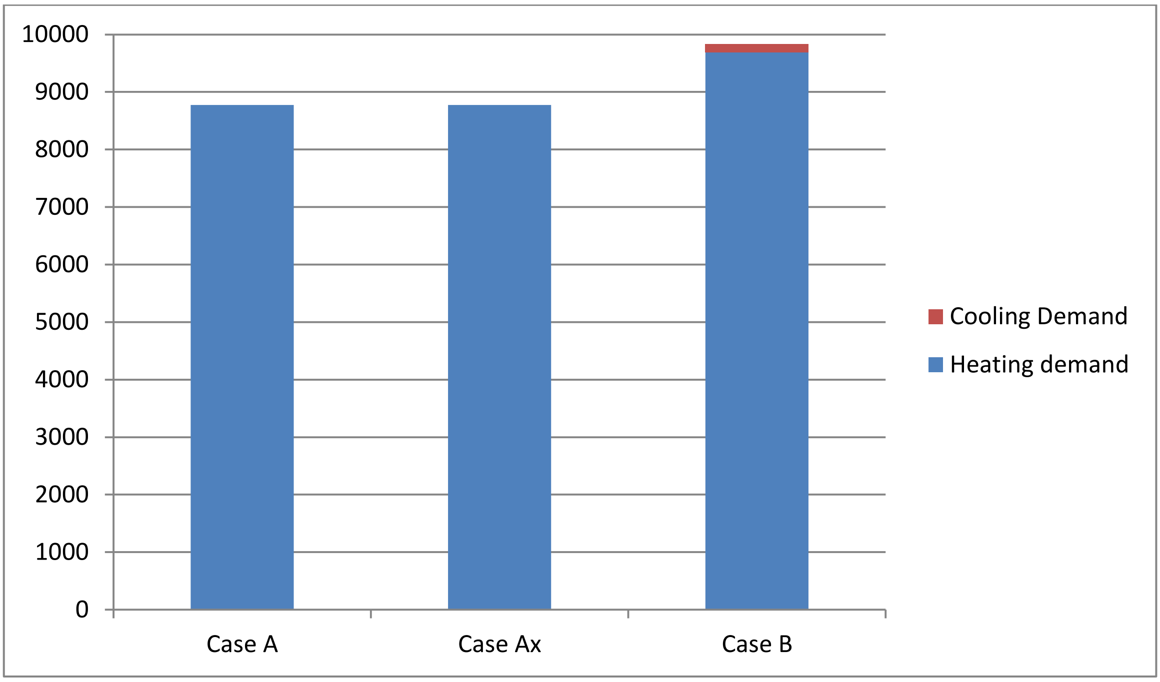


Figure 43: Energy demand for cases without PCM

Figure 43 here is the energy demand of the base cases A, A_x and B without PCM applied to the model. The energy demand of the both cases without cooling are almost the same but the third case B has relatively higher energy demand.

One of the reason for higher energy demand in case B is that, cooling system is applied to this case and the cooling demand required adds up to the energy demand. However, the cooling is required only for a short period of time in the year and the cooling demand is only little, 137 kWh in this case.

Another reason for the increase in energy demand in this case is that the SHGC factor of the windows is lesser than that of other cases. The SHGC measures a fraction of solar heat that enters into the indoor through the window. The lower value of SHGC means lower solar transmission into the indoor.

Thus the lower value of solar heat gain coefficient (SHGC) resulted in the higher value of energy demand, comparing all three cases.

Similar graphs of energy demand are plotted for these three cases when PCM is applied to different components.

4.2.1. Energy demand, Cases with PCM on wall

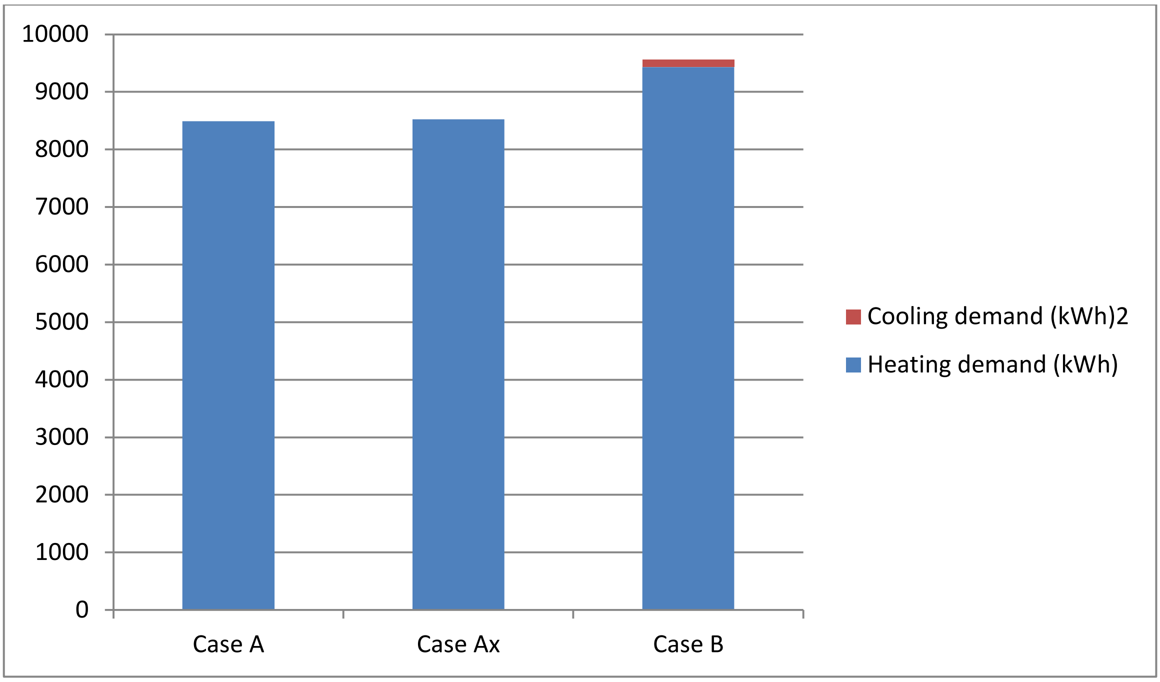


Figure 44: Energy demand for cases, PCM applied to wall

4.2.2. Case with PCM on Floor Base case A, A_x and B

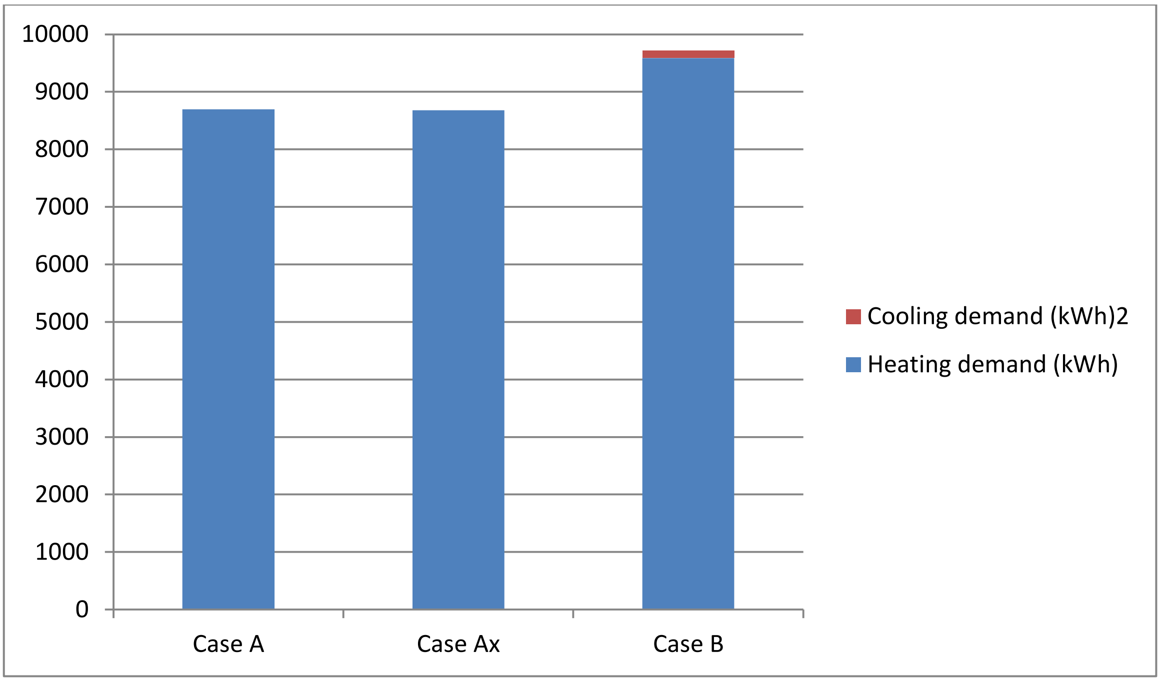


Figure 45: Energy demand of cases, PCM applied to floor

4.2.3. Case with PCM on wall and Floor Base case A, A_x and B

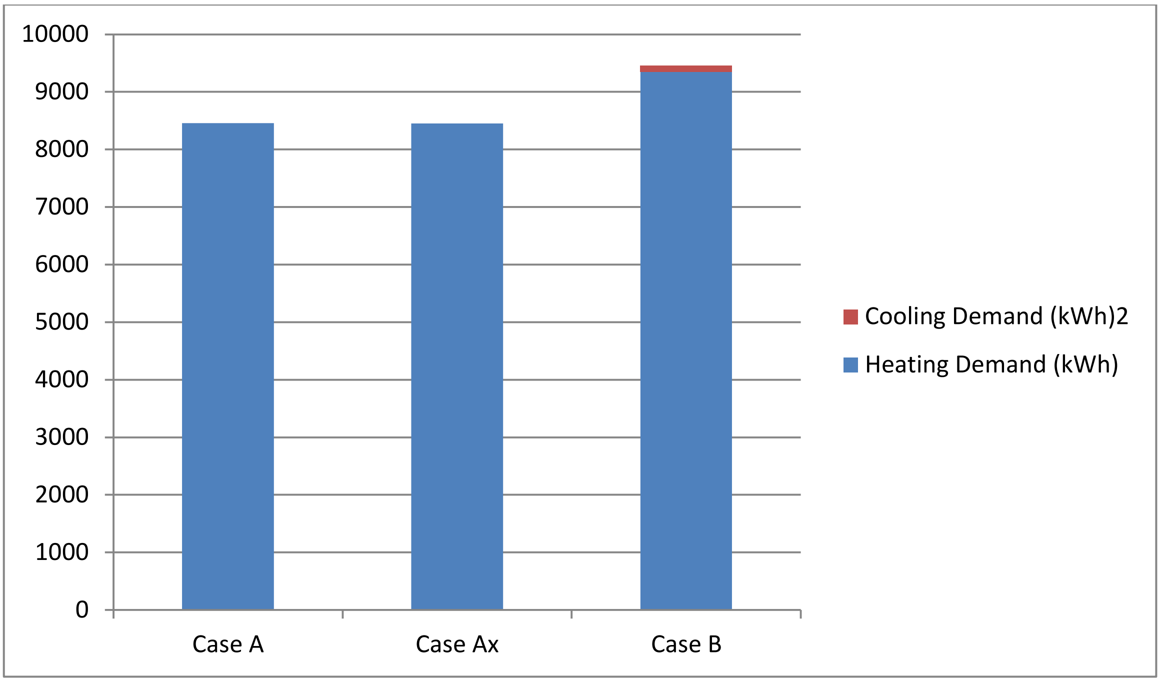


Figure 46: Energy demand for cases, PCM applied to wall and floor

These figures of energy demand plotted separately for different cases are combined together on the following bar diagram and the results are discussed.

4.2.4. Comparison of all the cases

All the results of energy demand for different simulations are put together in the figure 47 below and the Bar diagram is further discussed to compare the results.

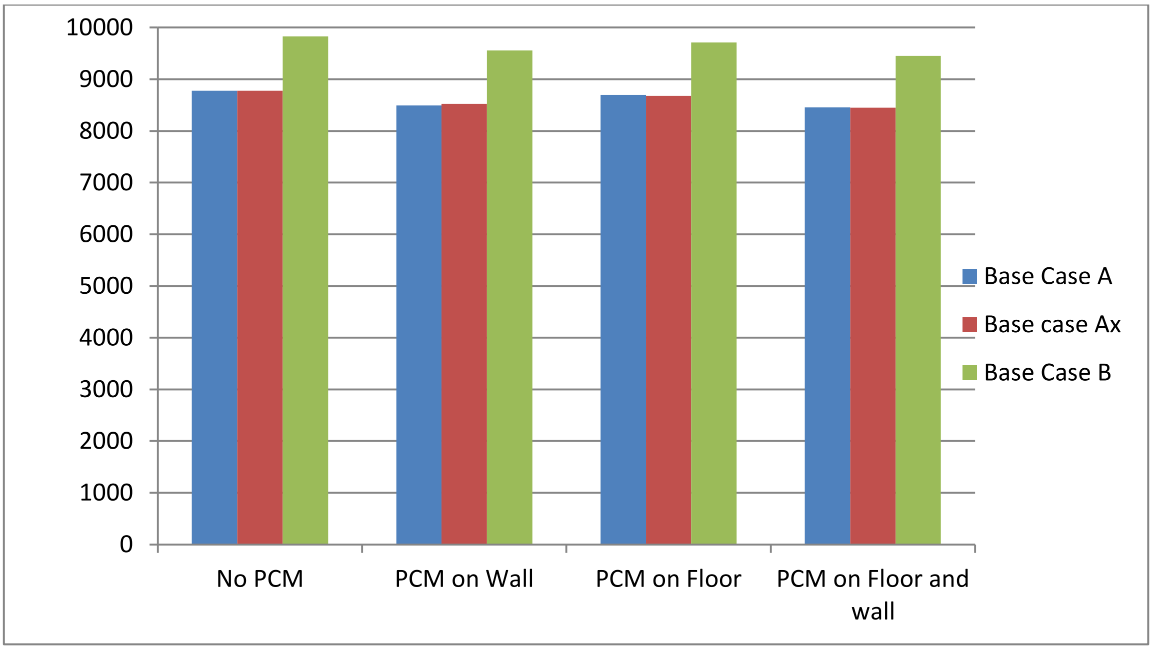


Figure 47 : Energy Demand comparison of different cases

Three different bars represent case A, A_x and B for different conditions of PCM application to these cases. As already discussed on the figure 43, the energy demand of case B is slightly higher than other cases.

Now if we compare two different condition of PCM application, for instance if we compare the energy demand of cases when no PCM is applied to the energy demand of case when PCM is applied to the wall of floor, the result does not show much difference. The application of PCM does not have a large effect on the resulting energy demand except for slight reduction in energy demand.

The values of energy demand for all the cases are documented on the table below.

Table 38: Compilation of all the Results

	Heating Demand (kWh)	Cooling Demand (kWh)	Total energy demand (kWh)	Max. IA temperature (°C)	Min. IA temperature (°C)
Base Case-A	8775	-	8775	42	19
PCM on Wall	8490.4	-	8490.4	41.1	19
PCM on Floor	8698.1	-	8696.1	41.7	19
PCM on floor and wall	8458.5	-	8458.5	40	19
Base Case- A_x	8775	-	8775	40.8	19
PCM on Wall	8487.5	-	8457.5	40.1	19
PCM on floor	8680.6	-	8680.6	40.4	19
PCM on floor and wall	8450	-	8450	39.2	19
Base Case- B	9694.1	-137	9831.1	27	19
PCM on Wall	9431.7	-124.7	9556.4	27	19
PCM on floor	9588.4	-125.8	9714.2	27	19
PCM on floor and wall	9345.2	-108.3	9453.5	27	19

Chapter 5

5.0. Conclusion and Further works

5.1 Conclusion

The aim of this thesis was initially set to look into the effect of PCM application on the energy use and Indoor temperature factors. The effect of various design conditions on the performance of PCM is also shown.

Table 37 and 38 on the discussion chapter, i.e. chapter 4 illustrates all the important results of IA temperature and energy demand of the simulated model. The results of various cases of the models show that the IA temperature depends on different parameters of window and the heating and cooling systems applied to the design. The defined models are simulated in WUFI Plus to achieve IA temperature in different design condition with PCM on various components. Table 34 summarizes the result of IA temperature for different cases of PCM. The area of PCM in associated design is a major factor that affects the IA temperature.

Similarly for the energy demand, comparison of the cases shows that application of PCM helps to lessen the energy demand to some extent. Besides, the parameters and design condition of window accounts largely for the higher energy demand of a building.

The case A_x among the discussed cases in this report shows a balanced result for IA and energy demand. The IA condition can be further improved by using PCM on various components. That of course cases some positive impact to the energy use of the building.

5.2. Further works

All the works of study and simulations presented here in this report are the result of intense work for short period of time. Due to limitation of time and resources, the discussions done here only covers certain aspects of simulation. The WUFI Plus and PCM related to this report have a large scope and vast range of research. Further investigation of the PCM can be done by changing the parameters on the simulation to see the effect on the behavior of PCM.

- Simulating the model in different climatic condition to see the effect of climate on the results of PCM behavior.
- During the assembly of model, it is considered that the U-value of the building components is same throughout the section i.e. no thermal bridges are taken in account. It will be useful to see the effect on results when the model is detailed.
- Also during simulation with WUFI Plus, the calculations are done only for thermal criteria. The other aspect, effect of moisture calculation can also be stimulating result to see.

References and Annexes

Standards

- NS 3031:2007 Norwegian Standard, Calculation of energy performance of building methodology and data
- ANSI/ASHRAE standard 55 : Thermal Environmental Conditions for Human Occupancy
- NS 3700, 2010: Norwegian Standard, Criteria for passive houses and low energy houses, Residential buildings.
- Guidance on technical requirements for construction, chapter 14; Energy

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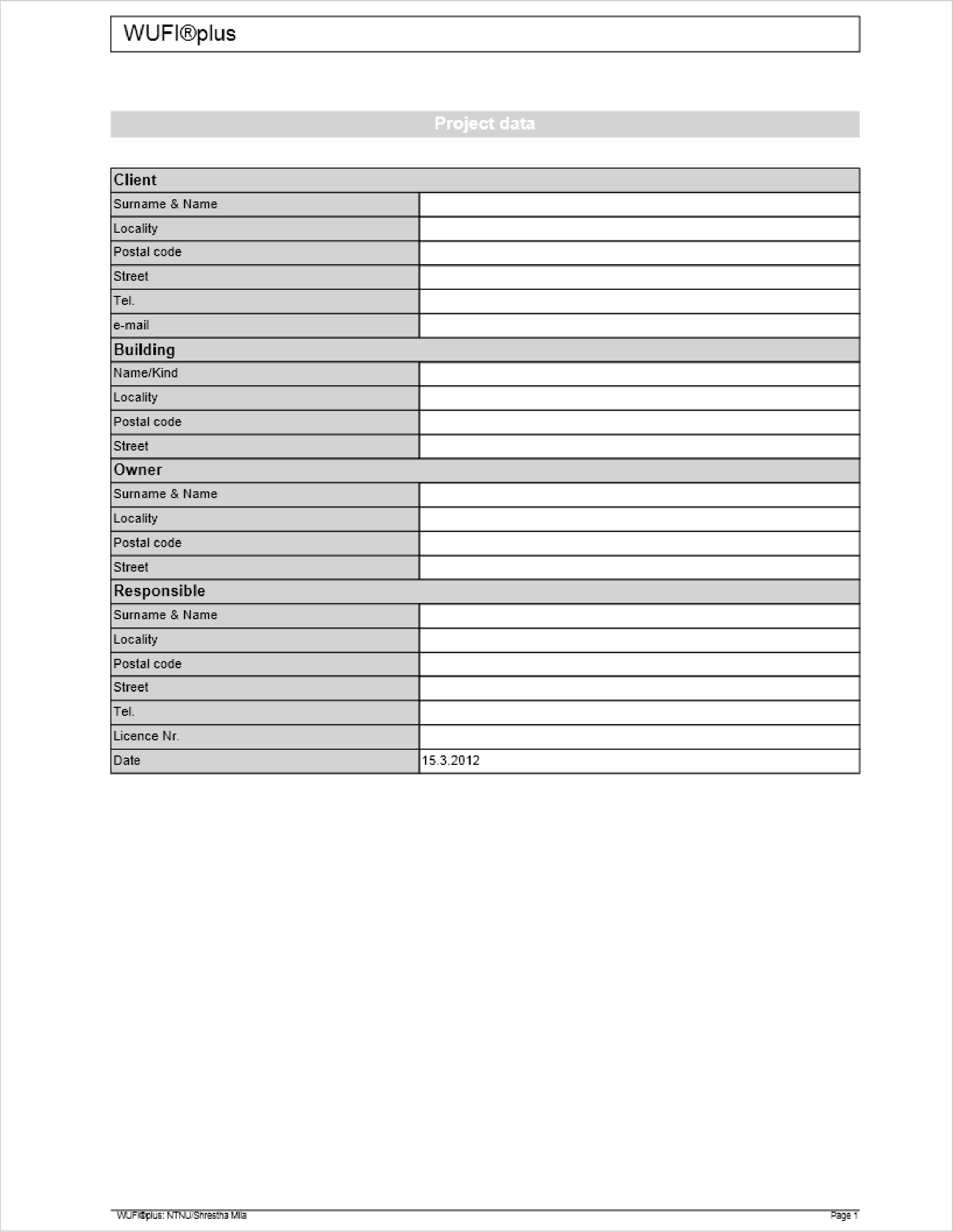
- Data Sheet measured properties of DuPont Energain, Available: http://energain.co.uk/Energain/en_GB/assets/downloads/tech_info/dupont_energain_datasheet.pdf. (Last Accessed: June, 2012)
- Most of the journals and articles referred from : http://www.sciencedirect.com/

ANNEX – I

Complete result of WUFI Plus simulation



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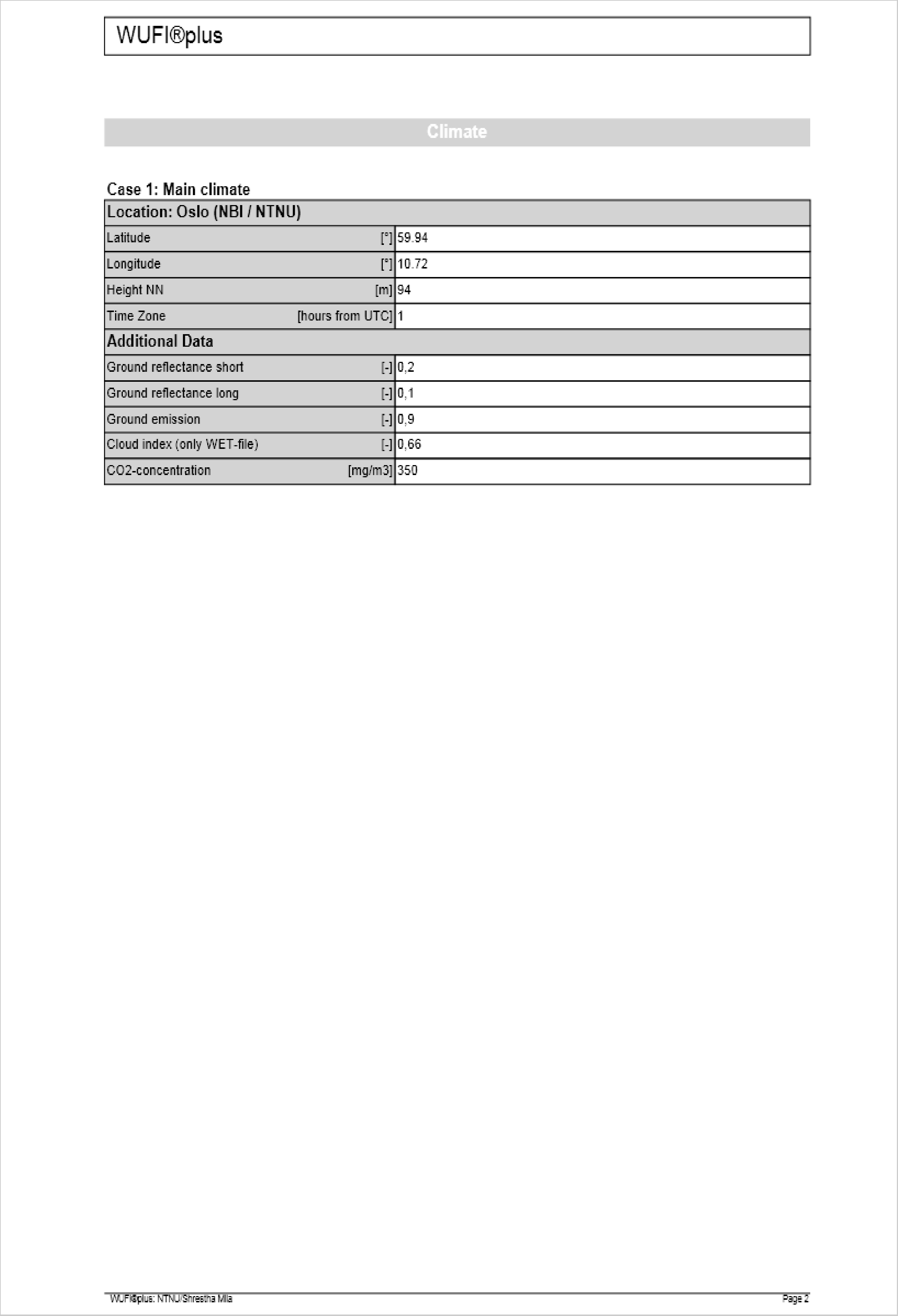
Project data

Client	
Surname & Name	
Locality	
Postal code	
Street	
Tel.	
e-mail	
Building	
Name/Kind	
Locality	
Postal code	
Street	
Owner	
Surname & Name	
Locality	
Postal code	
Street	
Responsible	
Surname & Name	
Locality	
Postal code	
Street	
Tel.	
Licence Nr.	
Date	15.3.2012

WUFI®plus: NTNU/Shrestha Mila Page 1



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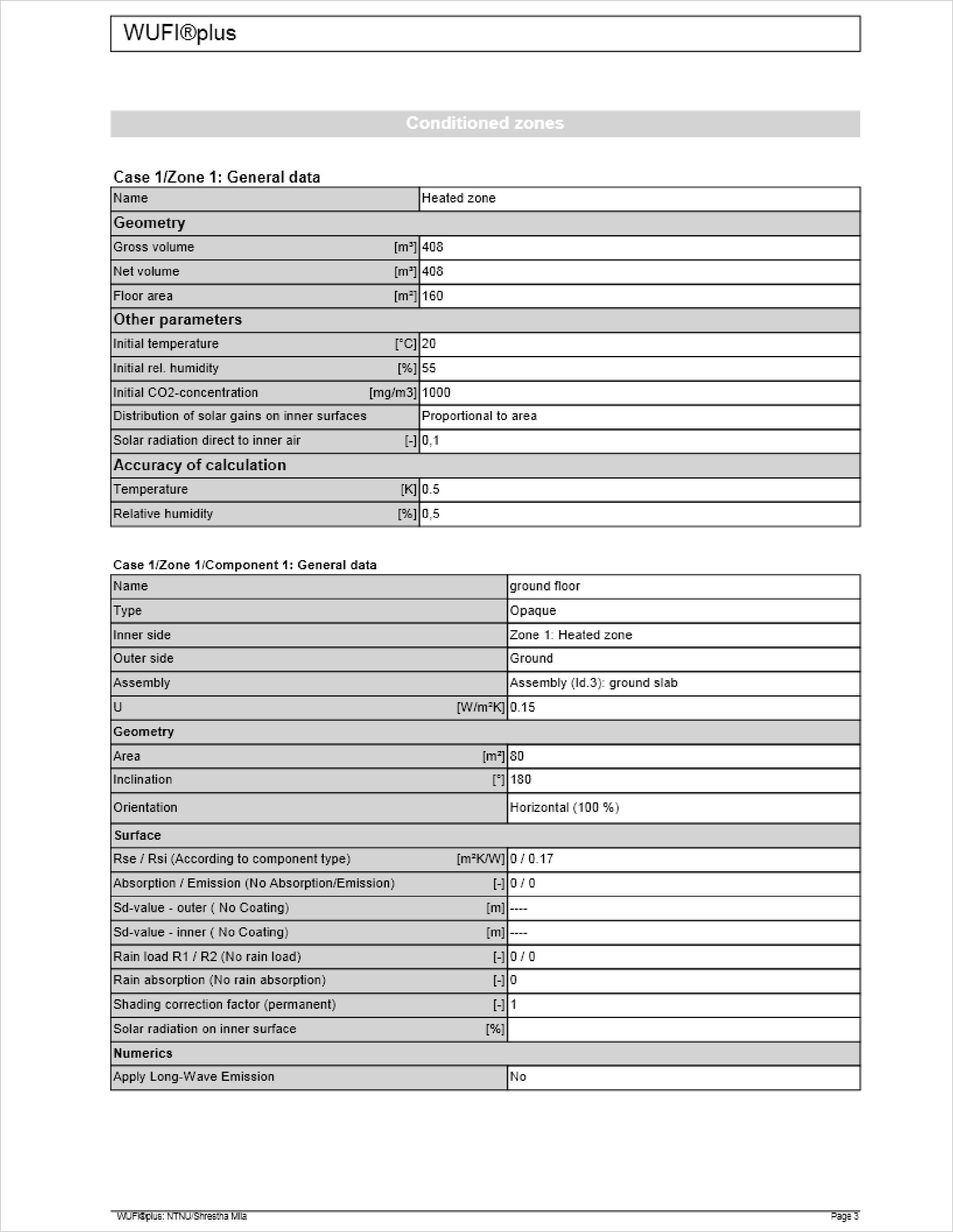
Climate

Case 1: Main climate

Location: Oslo (NBI / NTNU)		
Latitude	[°]	59.94
Longitude	[°]	10.72
Height NN	[m]	94
Time Zone	[hours from UTC]	1
Additional Data		
Ground reflectance short	[-]	0,2
Ground reflectance long	[-]	0,1
Ground emission	[-]	0,9
Cloud index (only WET-file)	[-]	0,66
CO2-concentration	[mg/m3]	350



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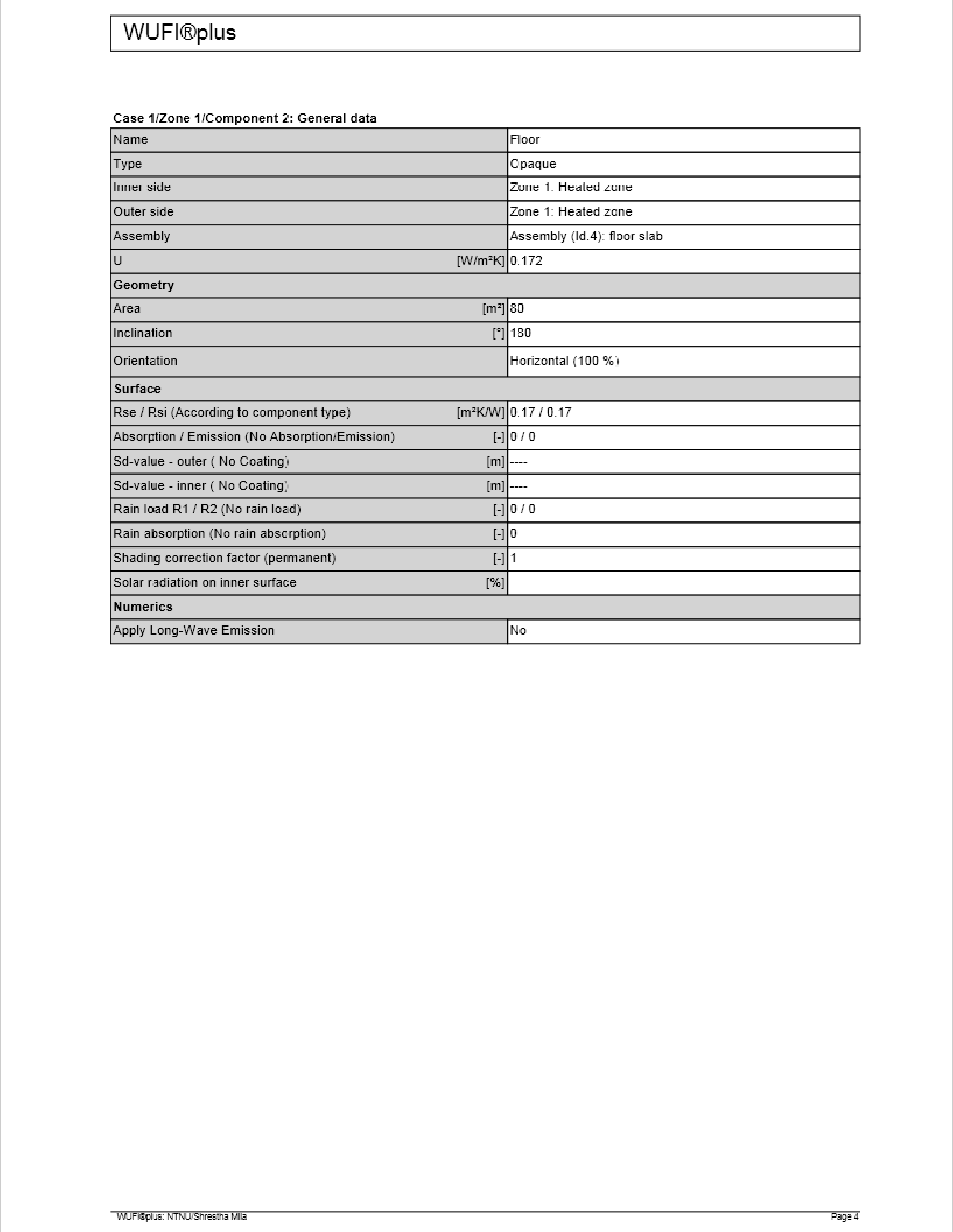
Conditioned zones

Case 1/Zone 1: General data

Name		Heated zone
Geometry		
Gross volume	[m^3]	408
Net volume	[m^3]	408
Floor area	[m^2]	160
Other parameters		
Initial temperature	[°C]	20
Initial rel. humidity	[%]	55
Initial CO2-concentration	[mg/m3]	1000
Distribution of solar gains on inner surfaces		Proportional to area
Solar radiation direct to inner air	[-]	0,1
Accuracy of calculation		
Temperature	[K]	0.5
Relative humidity	[%]	0,5

Case 1/Zone 1/Component 1: General data

Name		ground floor
Type		Opaque
Inner side		Zone 1: Heated zone
Outer side		Ground
Assembly		Assembly (Id.3): ground slab
U	[W/m^{2}K]	0.15
Geometry		
Area	[m^2]	80
Inclination	[°]	180
Orientation		Horizontal (100 %)
Surface		
Rse / Rsi (According to component type)	[m^{2}K/W]	0 / 0.17
Absorption / Emission (No Absorption/Emission)	[-]	0 / 0
Sd-value - outer (No Coating)	[m]	----
Sd-value - inner (No Coating)	[m]	----
Rain load R1 / R2 (No rain load)	[-]	0 / 0
Rain absorption (No rain absorption)	[-]	0
Shading correction factor (permanent)	[-]	1
Solar radiation on inner surface	[%]	
Numerics		
Apply Long-Wave Emission		No



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Case 1/Zone 1/Component 2: General data

Name		Floor
Type		Opaque
Inner side		Zone 1: Heated zone
Outer side		Zone 1: Heated zone
Assembly		Assembly (Id.4): floor slab
U	[W/m²K]	0.172
Geometry		
Area	[m²]	80
Inclination	[°]	180
Orientation		Horizontal (100 %)
Surface		
Rse / Rsi (According to component type)	[m²K/W]	0.17 / 0.17
Absorption / Emission (No Absorption/Emission)	[-]	0 / 0
Sd-value - outer (No Coating)	[m]	----
Sd-value - inner (No Coating)	[m]	----
Rain load R1 / R2 (No rain load)	[-]	0 / 0
Rain absorption (No rain absorption)	[-]	0
Shading correction factor (permanent)	[-]	1
Solar radiation on inner surface	[%]	
Numerics		
Apply Long-Wave Emission		No

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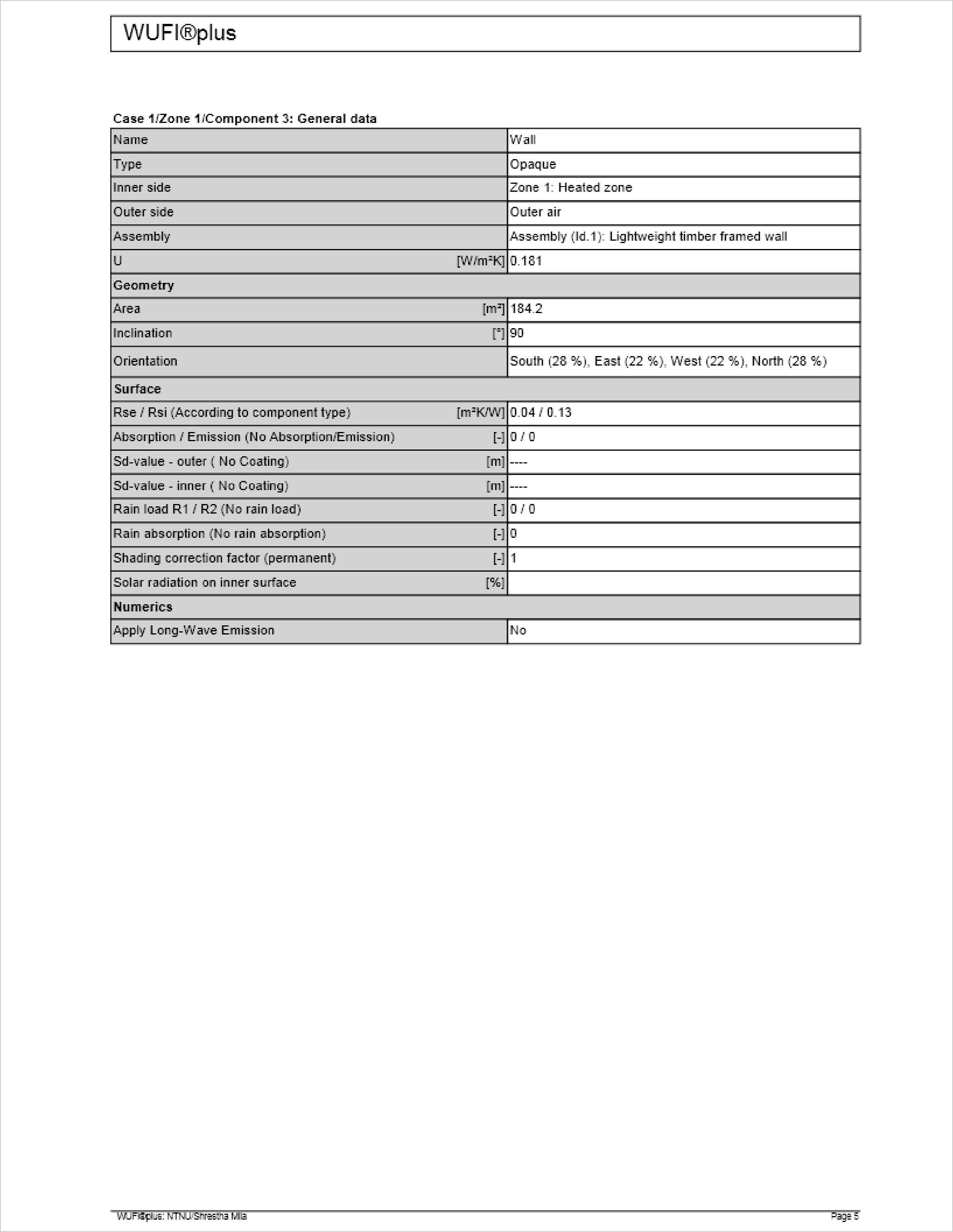

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Case 1/Zone 1/Component 3: General data

Name		Wall
Type		Opaque
Inner side		Zone 1: Heated zone
Outer side		Outer air
Assembly		Assembly (Id.1): Lightweight timber framed wall
U	[W/m²K]	0.181
Geometry		
Area	[m²]	184.2
Inclination	[°]	90
Orientation		South (28 %), East (22 %), West (22 %), North (28 %)
Surface		
Rse / Rsi (According to component type)	[m²K/W]	0.04 / 0.13
Absorption / Emission (No Absorption/Emission)	[-]	0 / 0
Sd-value - outer (No Coating)	[m]	----
Sd-value - inner (No Coating)	[m]	----
Rain load R1 / R2 (No rain load)	[-]	0 / 0
Rain absorption (No rain absorption)	[-]	0
Shading correction factor (permanent)	[-]	1
Solar radiation on inner surface	[%]	
Numerics		
Apply Long-Wave Emission		No

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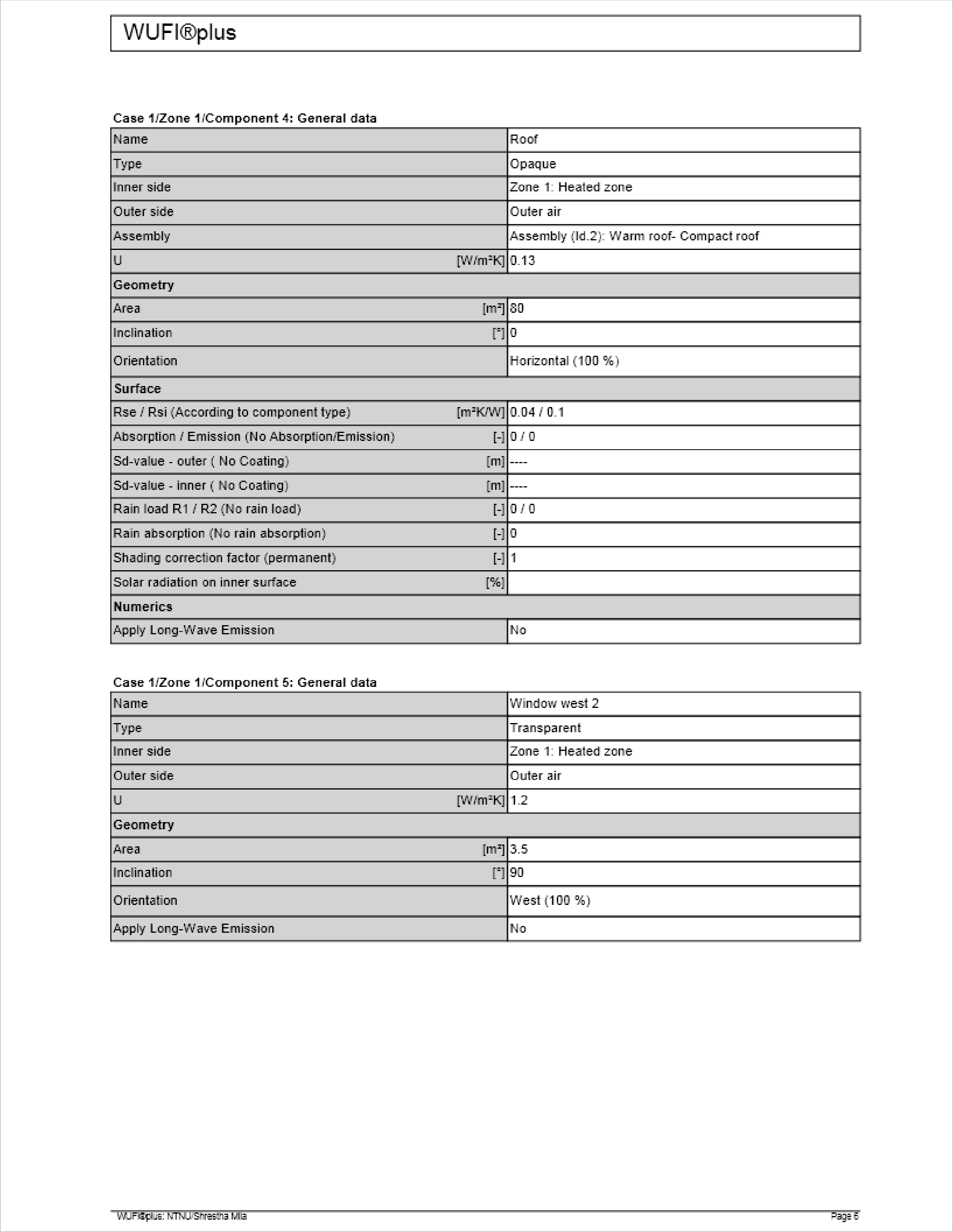

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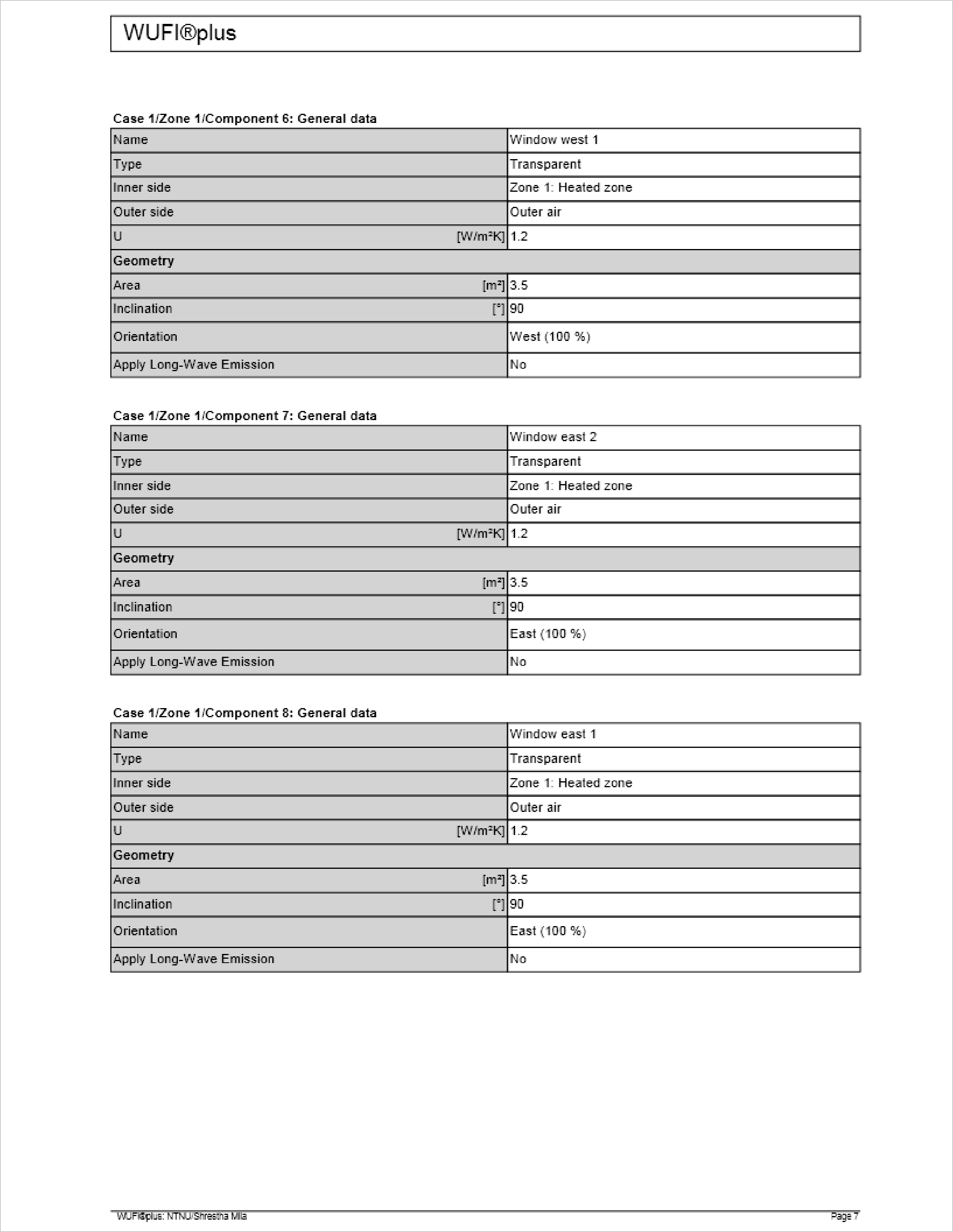
Case 1/Zone 1/Component 4: General data

Name	Roof
Type	Opaque
Inner side	Zone 1: Heated zone
Outer side	Outer air
Assembly	Assembly (Id.2): Warm roof- Compact roof
U [W/m²K]	0.13
Geometry	
Area [m²]	80
Inclination [°]	0
Orientation	Horizontal (100 %)
Surface	
Rse / Rsi (According to component type) [m²K/W]	0.04 / 0.1
Absorption / Emission (No Absorption/Emission) [-]	0 / 0
Sd-value - outer (No Coating) [m]	----
Sd-value - inner (No Coating) [m]	----
Rain load R1 / R2 (No rain load) [-]	0 / 0
Rain absorption (No rain absorption) [-]	0
Shading correction factor (permanent) [-]	1
Solar radiation on inner surface [%]	
Numerics	
Apply Long-Wave Emission	No

Case 1/Zone 1/Component 5: General data

Name	Window west 2
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m²K]	1.2
Geometry	
Area [m²]	3.5
Inclination [°]	90
Orientation	West (100 %)
Apply Long-Wave Emission	No



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Case 1/Zone 1/Component 6: General data

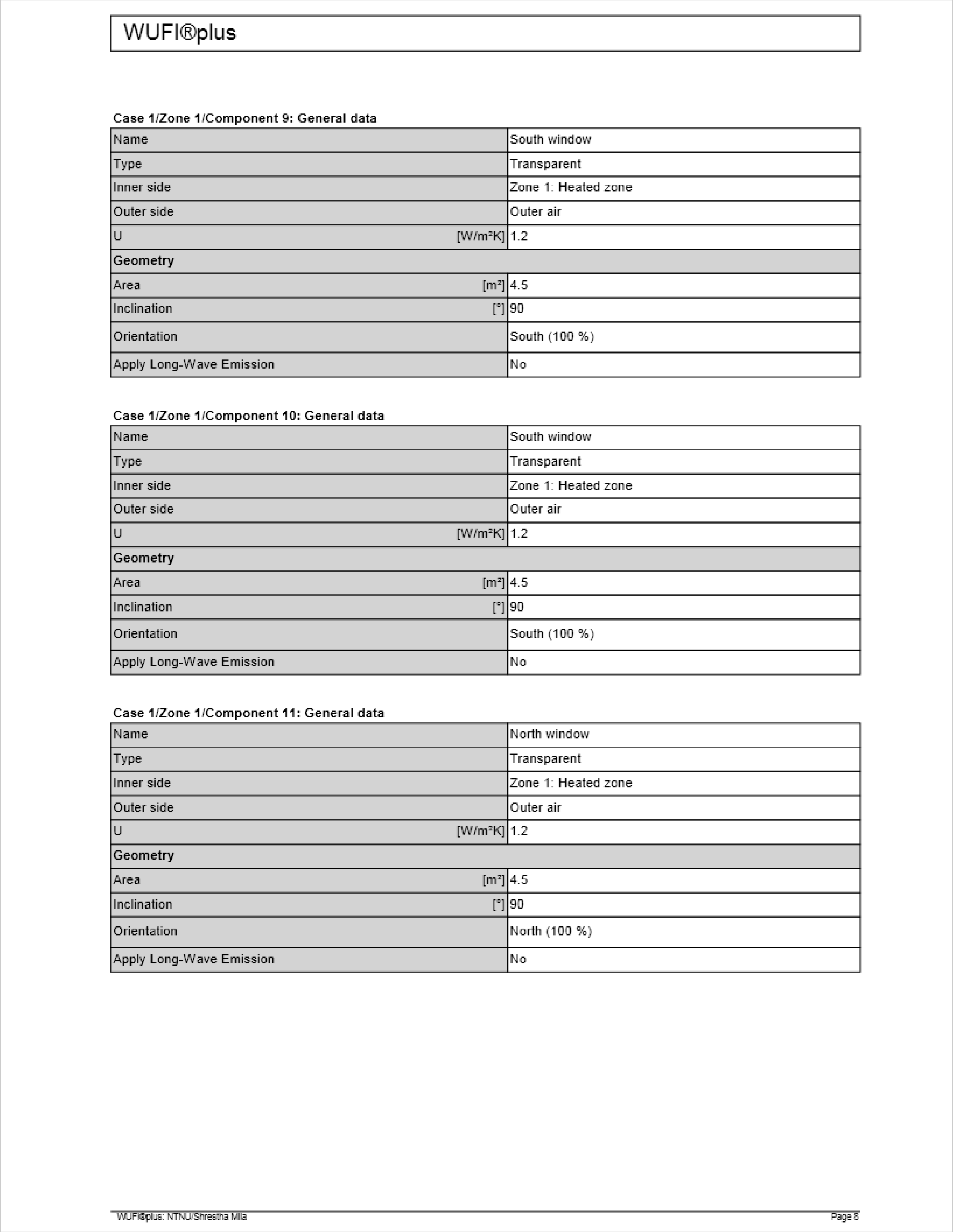
Name	Window west 1
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m²K]	1.2
Geometry	
Area [m²]	3.5
Inclination [°]	90
Orientation	West (100 %)
Apply Long-Wave Emission	No

Case 1/Zone 1/Component 7: General data

Name	Window east 2
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m²K]	1.2
Geometry	
Area [m²]	3.5
Inclination [°]	90
Orientation	East (100 %)
Apply Long-Wave Emission	No

Case 1/Zone 1/Component 8: General data

Name	Window east 1
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m²K]	1.2
Geometry	
Area [m²]	3.5
Inclination [°]	90
Orientation	East (100 %)
Apply Long-Wave Emission	No



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Case 1/Zone 1/Component 9: General data

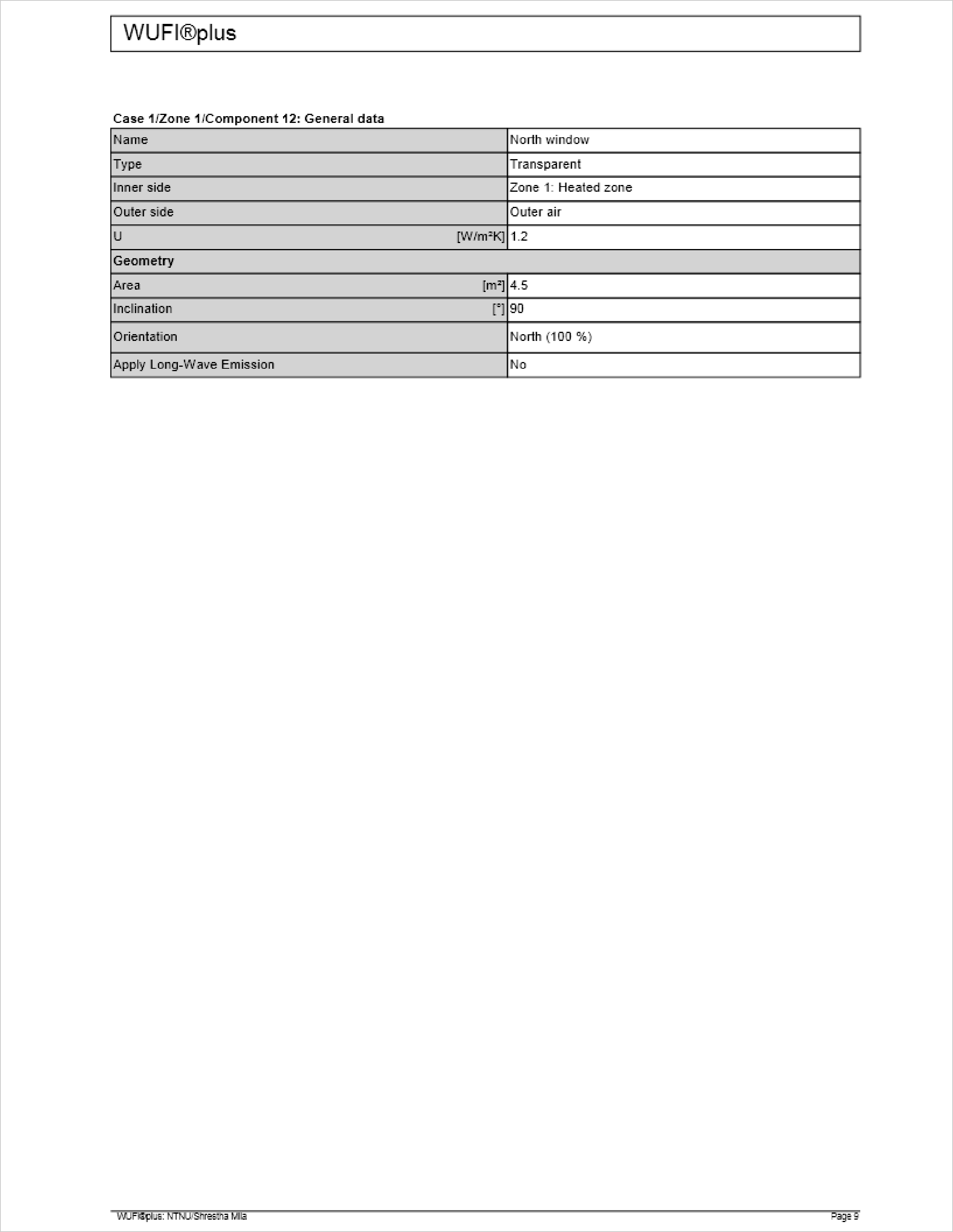
Name	South window
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m^{2}K]	1.2
Geometry	
Area [m^2]	4.5
Inclination [°]	90
Orientation	South (100 %)
Apply Long-Wave Emission	No

Case 1/Zone 1/Component 10: General data

Name	South window
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m^{2}K]	1.2
Geometry	
Area [m^2]	4.5
Inclination [°]	90
Orientation	South (100 %)
Apply Long-Wave Emission	No

Case 1/Zone 1/Component 11: General data

Name	North window
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m^{2}K]	1.2
Geometry	
Area [m^2]	4.5
Inclination [°]	90
Orientation	North (100 %)
Apply Long-Wave Emission	No



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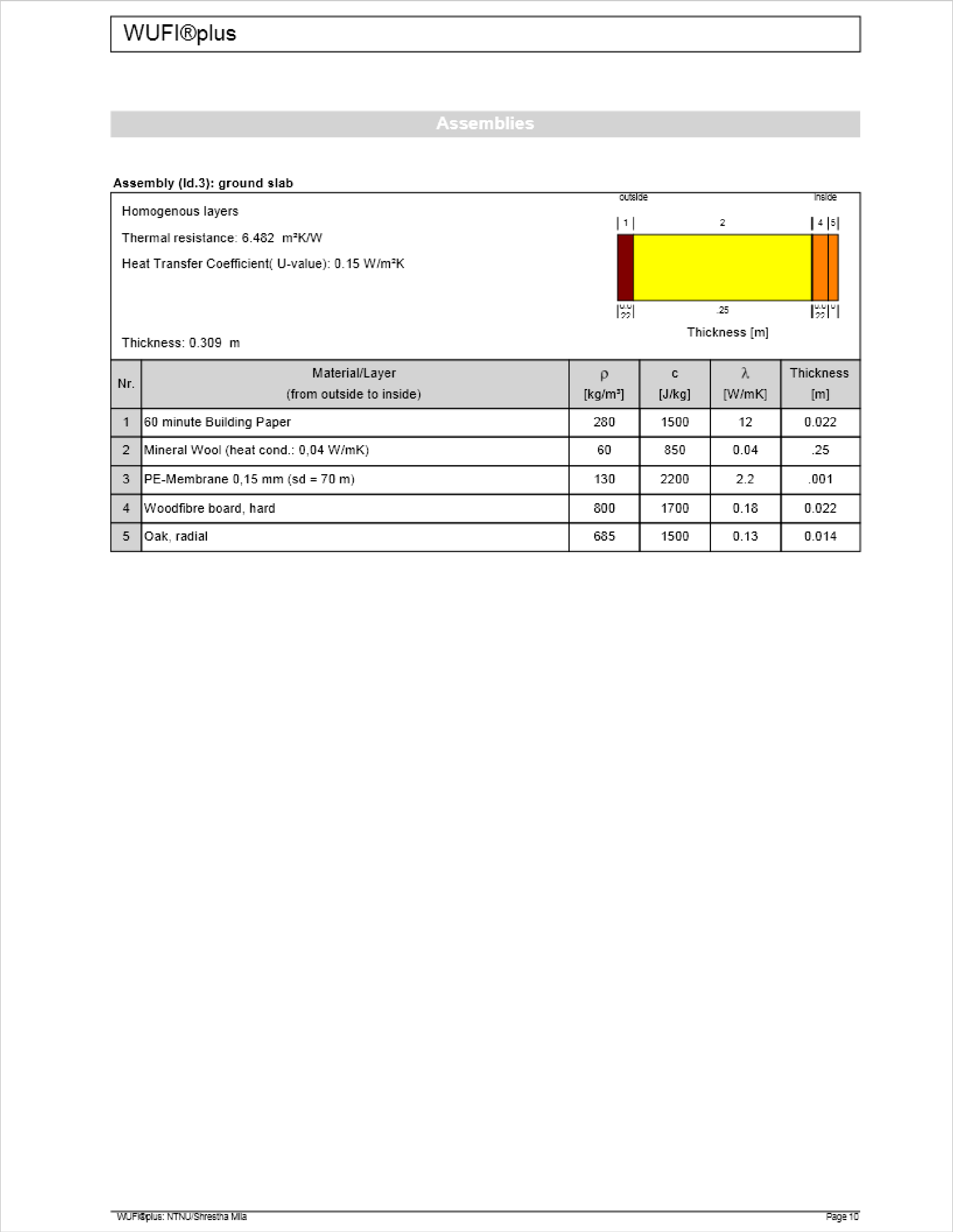
Case 1/Zone 1/Component 12: General data

Name	North window
Type	Transparent
Inner side	Zone 1: Heated zone
Outer side	Outer air
U [W/m²K]	1.2
Geometry	
Area [m²]	4.5
Inclination [°]	90
Orientation	North (100 %)
Apply Long-Wave Emission	No



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Assemblies

Assembly (Id.3): ground slab

Homogenous layers

Thermal resistance: 6.482 m²K/W

Heat Transfer Coefficient(U-value): 0.15 W/m²K

Thickness: 0.309 m

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kg]	λ [W/mK]	Thickness [m]
1	60 minute Building Paper	280	1500	12	0.022
2	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	.25
3	PE-Membrane 0,15 mm (sd = 70 m)	130	2200	2.2	.001
4	Woodfibre board, hard	800	1700	0.18	0.022
5	Oak, radial	685	1500	0.13	0.014

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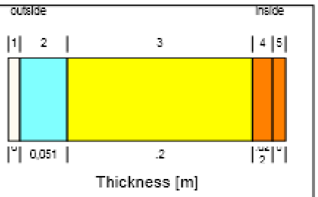
Assembly (Id.4): floor slab

Homogenous layers

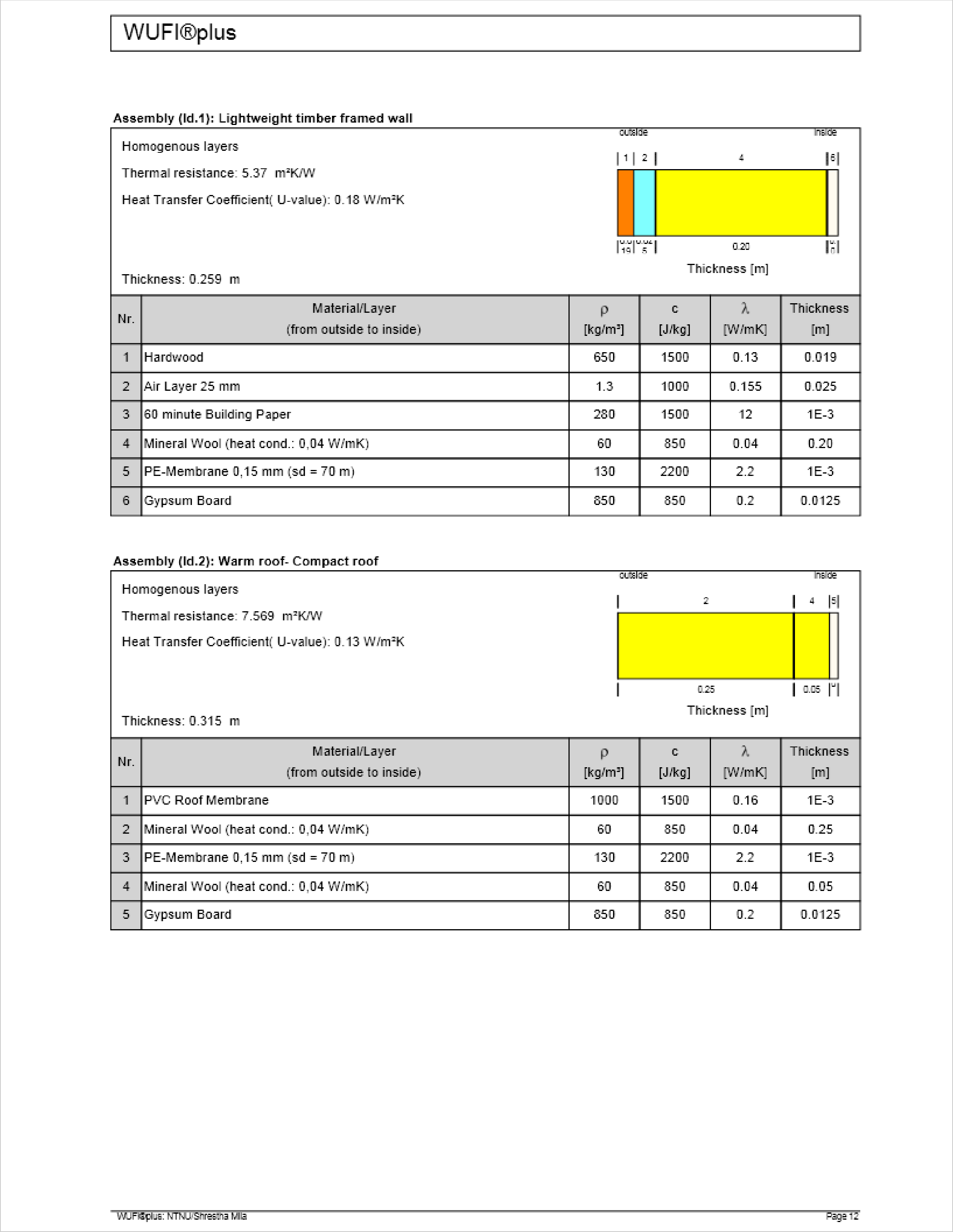
Thermal resistance: 5.475 m²K/W

Heat Transfer Coefficient(U-value): 0.17 W/m²K



Thickness: 0.3 m

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kg]	λ [W/mK]	Thickness [m]
1	Gypsum Board	850	850	0.2	0.0125
2	Air Layer 50 mm	1.3	1000	0.28	0,051
3	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	.2
4	Woodfibre board, hard	800	1700	0.18	.022
5	Oak, radial	685	1500	0.13	0.014



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Assembly (Id.1): Lightweight timber framed wall

Homogenous layers

Thermal resistance: 5.37 m²K/W

Heat Transfer Coefficient(U-value): 0.18 W/m²K

Thickness: 0.259 m

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kg]	λ [W/mK]	Thickness [m]
1	Hardwood	650	1500	0.13	0.019
2	Air Layer 25 mm	1.3	1000	0.155	0.025
3	60 minute Building Paper	280	1500	12	1E-3
4	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	0.20
5	PE-Membrane 0,15 mm (sd = 70 m)	130	2200	2.2	1E-3
6	Gypsum Board	850	850	0.2	0.0125

Assembly (Id.2): Warm roof- Compact roof

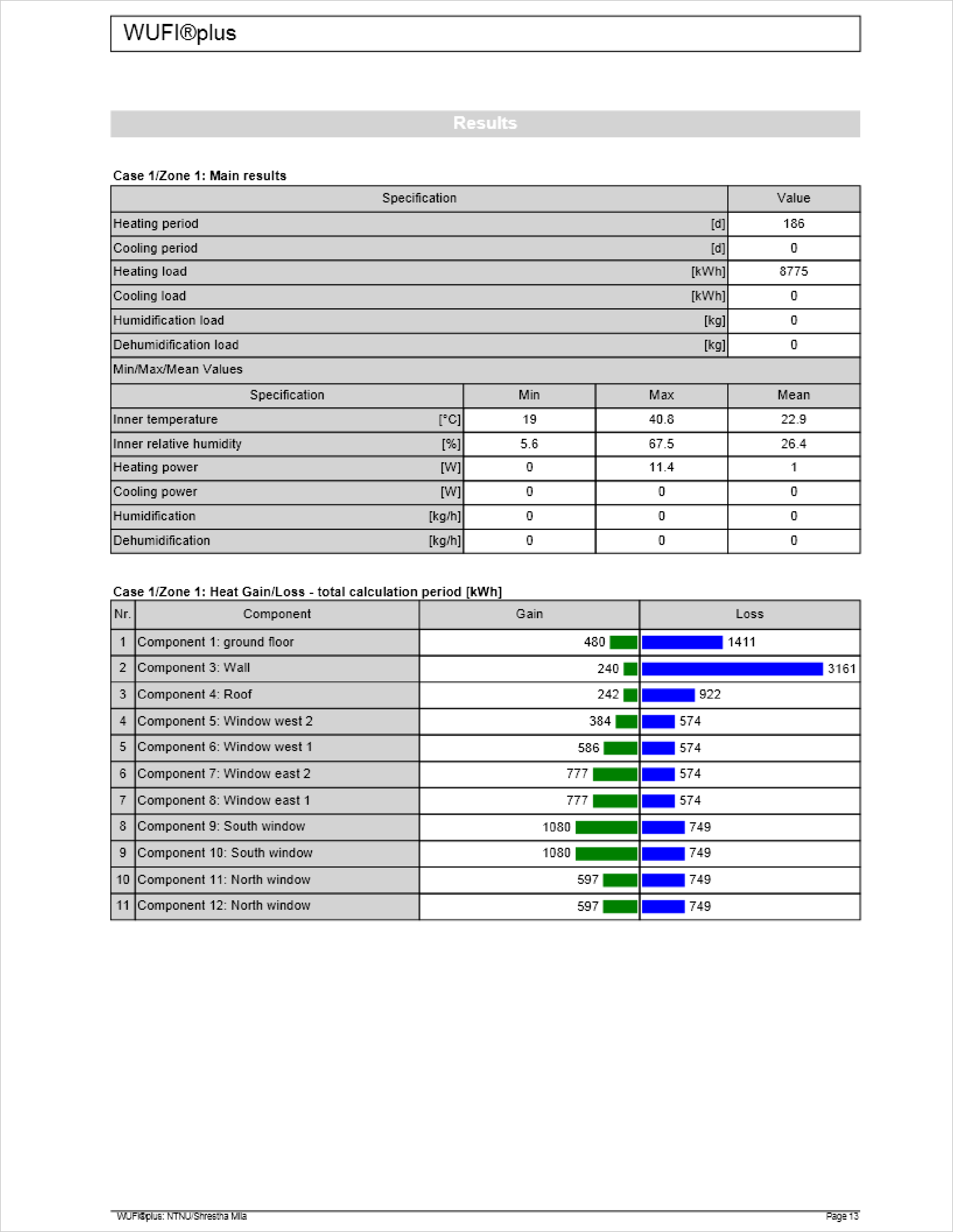
Homogenous layers

Thermal resistance: 7.569 m²K/W

Heat Transfer Coefficient(U-value): 0.13 W/m²K

Thickness: 0.315 m

Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kg]	λ [W/mK]	Thickness [m]
1	PVC Roof Membrane	1000	1500	0.16	1E-3
2	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	0.25
3	PE-Membrane 0,15 mm (sd = 70 m)	130	2200	2.2	1E-3
4	Mineral Wool (heat cond.: 0,04 W/mK)	60	850	0.04	0.05
5	Gypsum Board	850	850	0.2	0.0125



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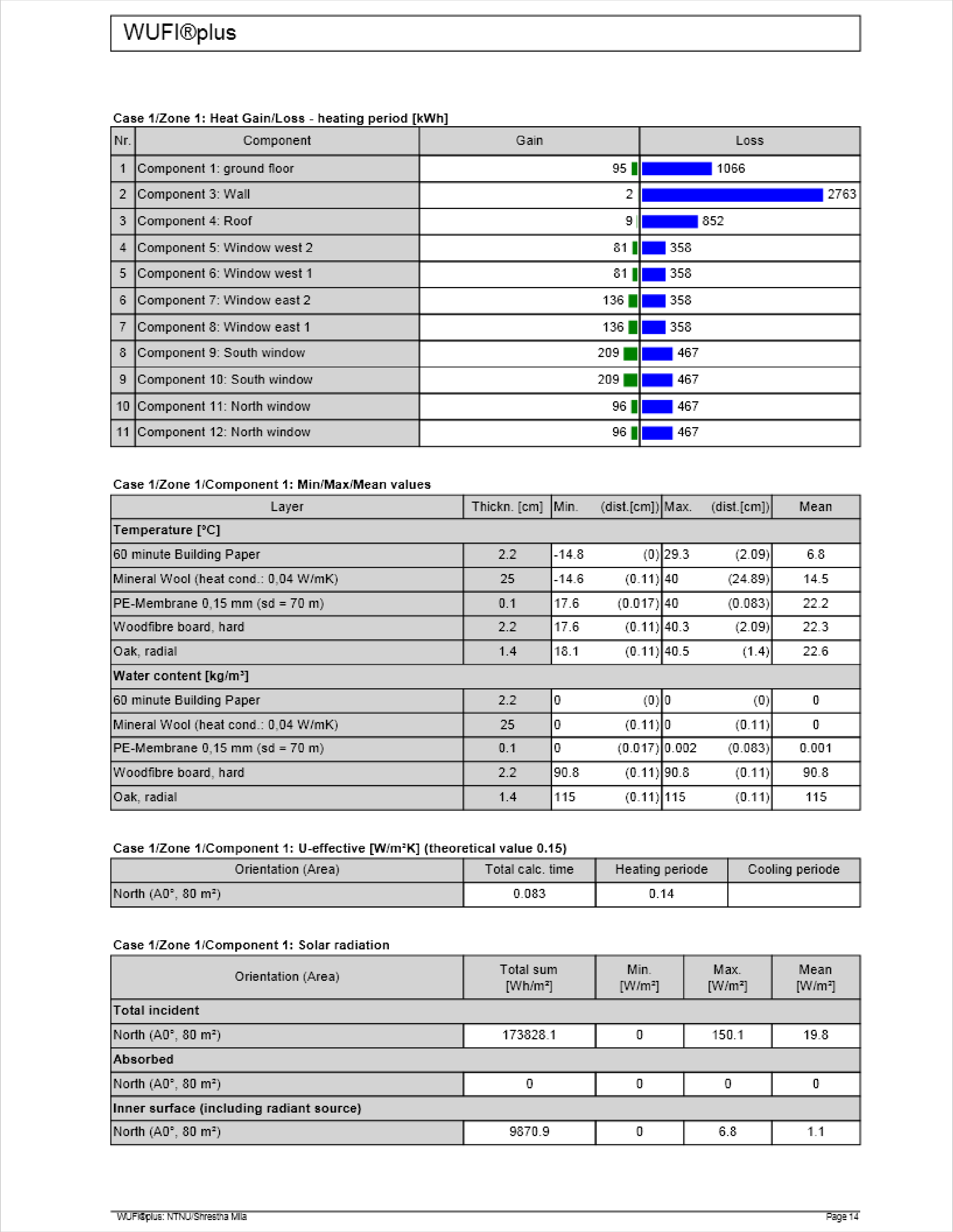
Results

Case 1/Zone 1: Main results

Specification			Value
Heating period [d]			186
Cooling period [d]			0
Heating load [kWh]			8775
Cooling load [kWh]			0
Humidification load [kg]			0
Dehumidification load [kg]			0
Min/Max/Mean Values			
Specification	Min	Max	Mean
Inner temperature [°C]	19	40.8	22.9
Inner relative humidity [%]	5.6	67.5	26.4
Heating power [W]	0	11.4	1
Cooling power [W]	0	0	0
Humidification [kg/h]	0	0	0
Dehumidification [kg/h]	0	0	0

Case 1/Zone 1: Heat Gain/Loss - total calculation period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: ground floor	480	1411
2	Component 3: Wall	240	3161
3	Component 4: Roof	242	922
4	Component 5: Window west 2	384	574
5	Component 6: Window west 1	586	574
6	Component 7: Window east 2	777	574
7	Component 8: Window east 1	777	574
8	Component 9: South window	1080	749
9	Component 10: South window	1080	749
10	Component 11: North window	597	749
11	Component 12: North window	597	749



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Case 1/Zone 1: Heat Gain/Loss - heating period [kWh]

Nr.	Component	Gain	Loss
1	Component 1: ground floor	95	1066
2	Component 3: Wall	2	2763
3	Component 4: Roof	9	852
4	Component 5: Window west 2	81	358
5	Component 6: Window west 1	81	358
6	Component 7: Window east 2	136	358
7	Component 8: Window east 1	136	358
8	Component 9: South window	209	467
9	Component 10: South window	209	467
10	Component 11: North window	96	467
11	Component 12: North window	96	467

Case 1/Zone 1/Component 1: Min/Max/Mean values

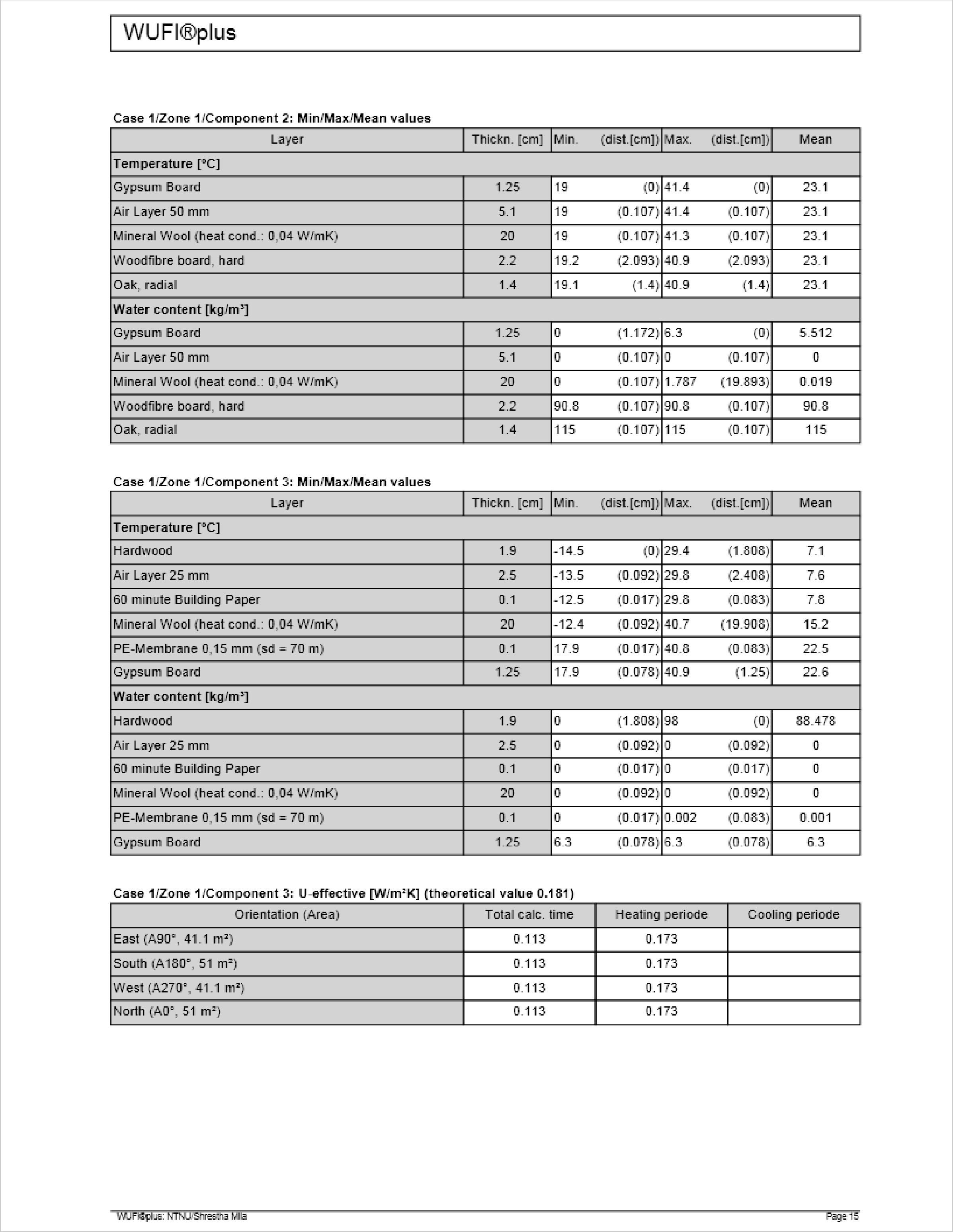
Layer	Thickn. [cm]	Min.	(dist.[cm])	Max.	(dist.[cm])	Mean
Temperature [°C]						
60 minute Building Paper	2.2	-14.8	(0)	29.3	(2.09)	6.8
Mineral Wool (heat cond.: 0,04 W/mK)	25	-14.6	(0.11)	40	(24.89)	14.5
PE-Membrane 0,15 mm (sd = 70 m)	0.1	17.6	(0.017)	40	(0.083)	22.2
Woodfibre board, hard	2.2	17.6	(0.11)	40.3	(2.09)	22.3
Oak, radial	1.4	18.1	(0.11)	40.5	(1.4)	22.6
Water content [kg/m³]						
60 minute Building Paper	2.2	0	(0)	0	(0)	0
Mineral Wool (heat cond.: 0,04 W/mK)	25	0	(0.11)	0	(0.11)	0
PE-Membrane 0,15 mm (sd = 70 m)	0.1	0	(0.017)	0.002	(0.083)	0.001
Woodfibre board, hard	2.2	90.8	(0.11)	90.8	(0.11)	90.8
Oak, radial	1.4	115	(0.11)	115	(0.11)	115

Case 1/Zone 1/Component 1: U-effective [W/m²K] (theoretical value 0.15)

Orientation (Area)	Total calc. time	Heating periode	Cooling periode
North (A0°, 80 m²)	0.083	0.14	

Case 1/Zone 1/Component 1: Solar radiation

Orientation (Area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
North (A0°, 80 m²)	173828.1	0	150.1	19.8
Absorbed				
North (A0°, 80 m²)	0	0	0	0
Inner surface (including radiant source)				
North (A0°, 80 m²)	9870.9	0	6.8	1.1



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Case 1/Zone 1/Component 2: Min/Max/Mean values

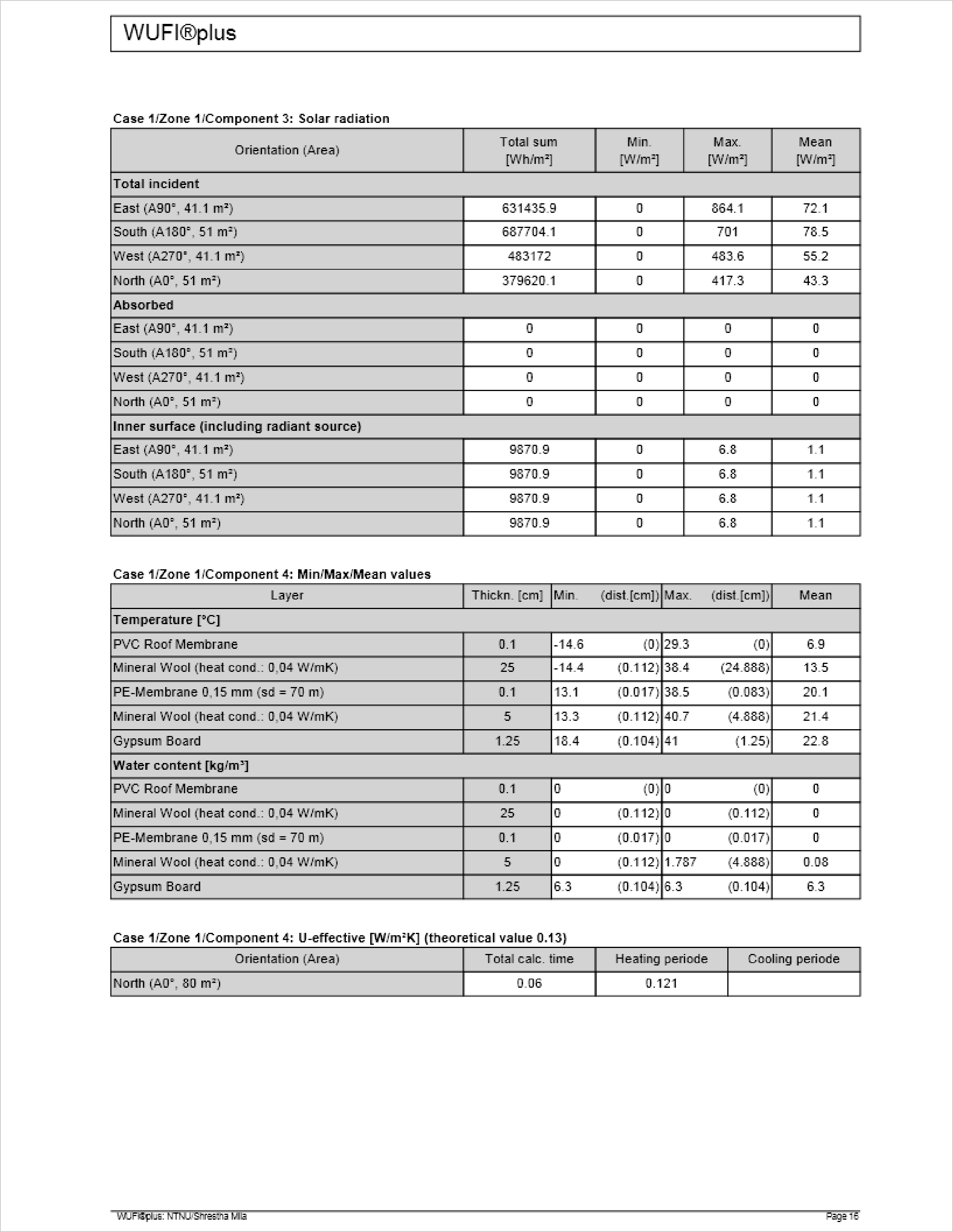
Layer	Thickn. [cm]	Min.	(dist.[cm])	Max.	(dist.[cm])	Mean
Temperature [°C]						
Gypsum Board	1.25	19	(0)	41.4	(0)	23.1
Air Layer 50 mm	5.1	19	(0.107)	41.4	(0.107)	23.1
Mineral Wool (heat cond.: 0,04 W/mK)	20	19	(0.107)	41.3	(0.107)	23.1
Woodfibre board, hard	2.2	19.2	(2.093)	40.9	(2.093)	23.1
Oak, radial	1.4	19.1	(1.4)	40.9	(1.4)	23.1
Water content [kg/m³]						
Gypsum Board	1.25	0	(1.172)	6.3	(0)	5.512
Air Layer 50 mm	5.1	0	(0.107)	0	(0.107)	0
Mineral Wool (heat cond.: 0,04 W/mK)	20	0	(0.107)	1.787	(19.893)	0.019
Woodfibre board, hard	2.2	90.8	(0.107)	90.8	(0.107)	90.8
Oak, radial	1.4	115	(0.107)	115	(0.107)	115

Case 1/Zone 1/Component 3: Min/Max/Mean values

Layer	Thickn. [cm]	Min.	(dist.[cm])	Max.	(dist.[cm])	Mean
Temperature [°C]						
Hardwood	1.9	-14.5	(0)	29.4	(1.808)	7.1
Air Layer 25 mm	2.5	-13.5	(0.092)	29.8	(2.408)	7.6
60 minute Building Paper	0.1	-12.5	(0.017)	29.8	(0.083)	7.8
Mineral Wool (heat cond.: 0,04 W/mK)	20	-12.4	(0.092)	40.7	(19.908)	15.2
PE-Membrane 0,15 mm (sd = 70 m)	0.1	17.9	(0.017)	40.8	(0.083)	22.5
Gypsum Board	1.25	17.9	(0.078)	40.9	(1.25)	22.6
Water content [kg/m³]						
Hardwood	1.9	0	(1.808)	98	(0)	88.478
Air Layer 25 mm	2.5	0	(0.092)	0	(0.092)	0
60 minute Building Paper	0.1	0	(0.017)	0	(0.017)	0
Mineral Wool (heat cond.: 0,04 W/mK)	20	0	(0.092)	0	(0.092)	0
PE-Membrane 0,15 mm (sd = 70 m)	0.1	0	(0.017)	0.002	(0.083)	0.001
Gypsum Board	1.25	6.3	(0.078)	6.3	(0.078)	6.3

Case 1/Zone 1/Component 3: U-effective [W/m²K] (theoretical value 0.181)

Orientation (Area)	Total calc. time	Heating periode	Cooling periode
East (A90°, 41.1 m²)	0.113	0.173	
South (A180°, 51 m²)	0.113	0.173	
West (A270°, 41.1 m²)	0.113	0.173	
North (A0°, 51 m²)	0.113	0.173	



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Case 1/Zone 1/Component 3: Solar radiation

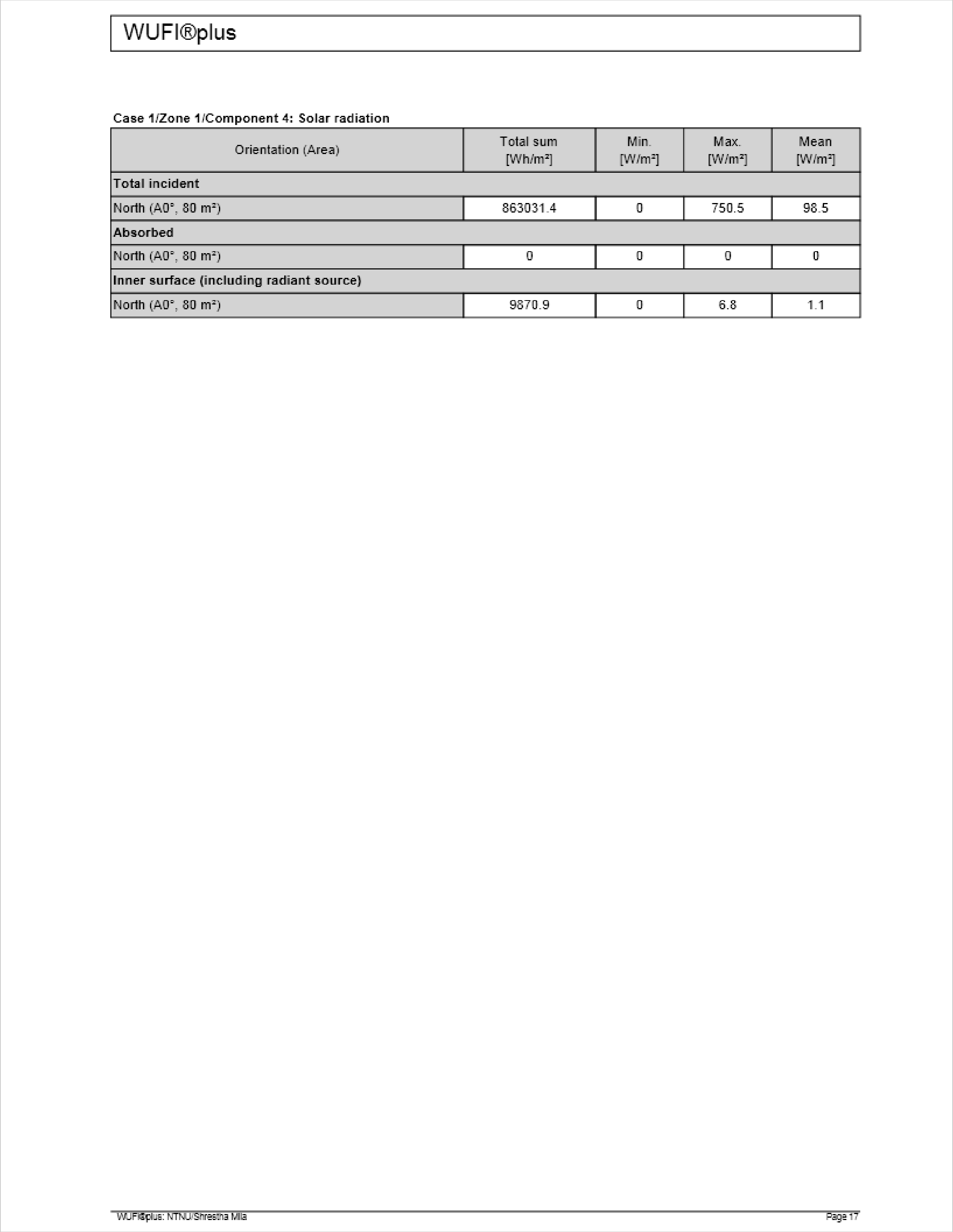
Orientation (Area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
East (A90°, 41.1 m²)	631435.9	0	864.1	72.1
South (A180°, 51 m²)	687704.1	0	701	78.5
West (A270°, 41.1 m²)	483172	0	483.6	55.2
North (A0°, 51 m²)	379620.1	0	417.3	43.3
Absorbed				
East (A90°, 41.1 m²)	0	0	0	0
South (A180°, 51 m²)	0	0	0	0
West (A270°, 41.1 m²)	0	0	0	0
North (A0°, 51 m²)	0	0	0	0
Inner surface (including radiant source)				
East (A90°, 41.1 m²)	9870.9	0	6.8	1.1
South (A180°, 51 m²)	9870.9	0	6.8	1.1
West (A270°, 41.1 m²)	9870.9	0	6.8	1.1
North (A0°, 51 m²)	9870.9	0	6.8	1.1

Case 1/Zone 1/Component 4: Min/Max/Mean values

Layer	Thickn. [cm]	Min.	(dist.[cm])	Max.	(dist.[cm])	Mean
Temperature [°C]						
PVC Roof Membrane	0.1	-14.6	(0)	29.3	(0)	6.9
Mineral Wool (heat cond.: 0,04 W/mK)	25	-14.4	(0.112)	38.4	(24.888)	13.5
PE-Membrane 0,15 mm (sd = 70 m)	0.1	13.1	(0.017)	38.5	(0.083)	20.1
Mineral Wool (heat cond.: 0,04 W/mK)	5	13.3	(0.112)	40.7	(4.888)	21.4
Gypsum Board	1.25	18.4	(0.104)	41	(1.25)	22.8
Water content [kg/m³]						
PVC Roof Membrane	0.1	0	(0)	0	(0)	0
Mineral Wool (heat cond.: 0,04 W/mK)	25	0	(0.112)	0	(0.112)	0
PE-Membrane 0,15 mm (sd = 70 m)	0.1	0	(0.017)	0	(0.017)	0
Mineral Wool (heat cond.: 0,04 W/mK)	5	0	(0.112)	1.787	(4.888)	0.08
Gypsum Board	1.25	6.3	(0.104)	6.3	(0.104)	6.3

Case 1/Zone 1/Component 4: U-effective [W/m²K] (theoretical value 0.13)

Orientation (Area)	Total calc. time	Heating periode	Cooling periode
North (A0°, 80 m²)	0.06	0.121	



WUFI®plus

Case 1/Zone 1/Component 4: Solar radiation

Orientation (Area)	Total sum [Wh/m²]	Min. [W/m²]	Max. [W/m²]	Mean [W/m²]
Total incident				
North (A0°, 80 m²)	863031.4	0	750.5	98.5
Absorbed				
North (A0°, 80 m²)	0	0	0	0
Inner surface (including radiant source)				
North (A0°, 80 m²)	9870.9	0	6.8	1.1

WUFI®plus: NTNU/Shrestha Mila

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WUFI®plus

Mould grow conditions

WUFI®plus: NTNU/Shrestha Mila

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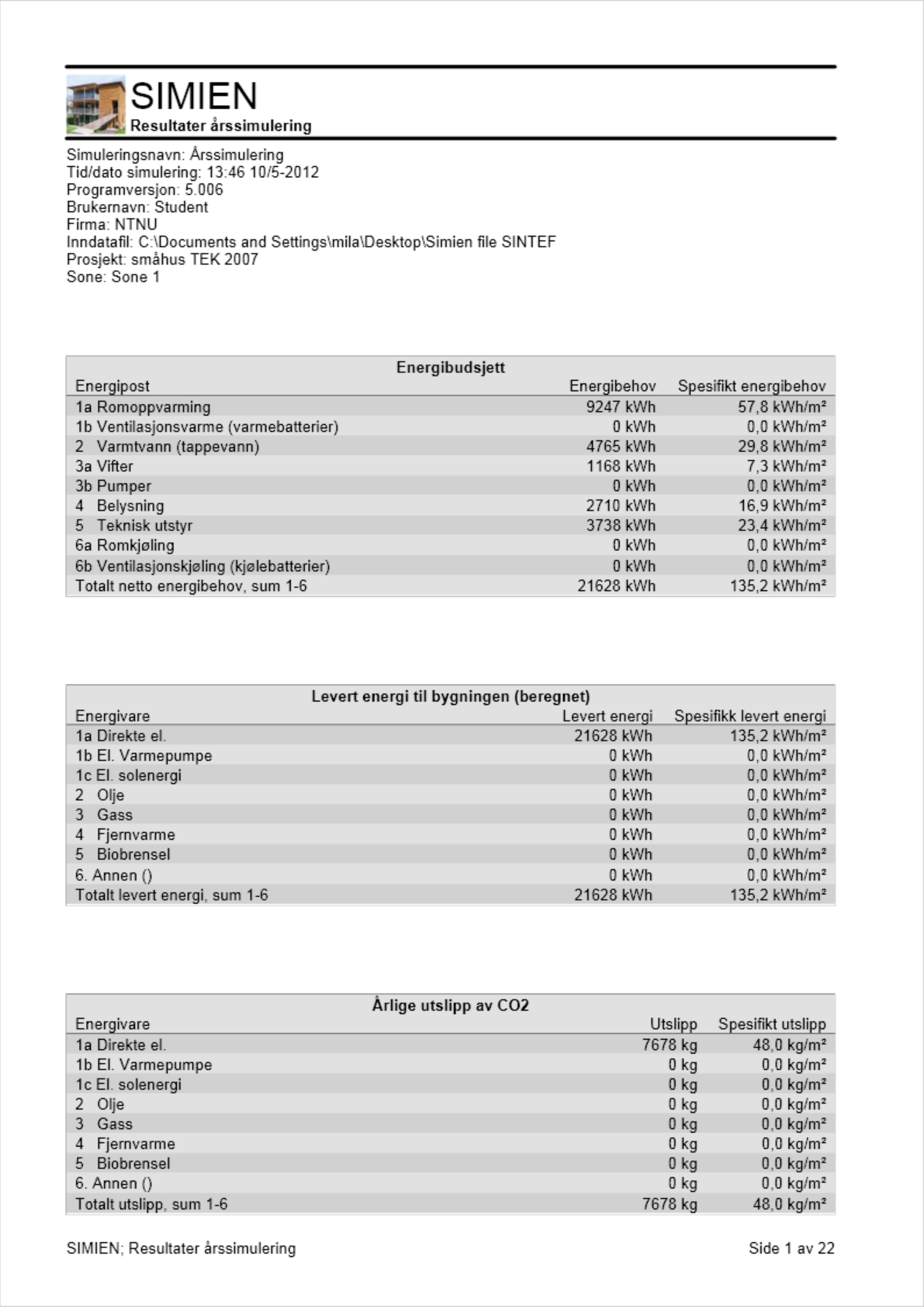
Annex - II

SIMIEN Results



SIMIEN

Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	9247 kWh	57,8 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	0 kWh	0,0 kWh/m²
2 Varmtvann (tappevann)	4765 kWh	29,8 kWh/m²
3a Vifter	1168 kWh	7,3 kWh/m²
3b Pumper	0 kWh	0,0 kWh/m²
4 Belysning	2710 kWh	16,9 kWh/m²
5 Teknisk utstyr	3738 kWh	23,4 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	21628 kWh	135,2 kWh/m²

Levert energi til bygningen (beregnet)

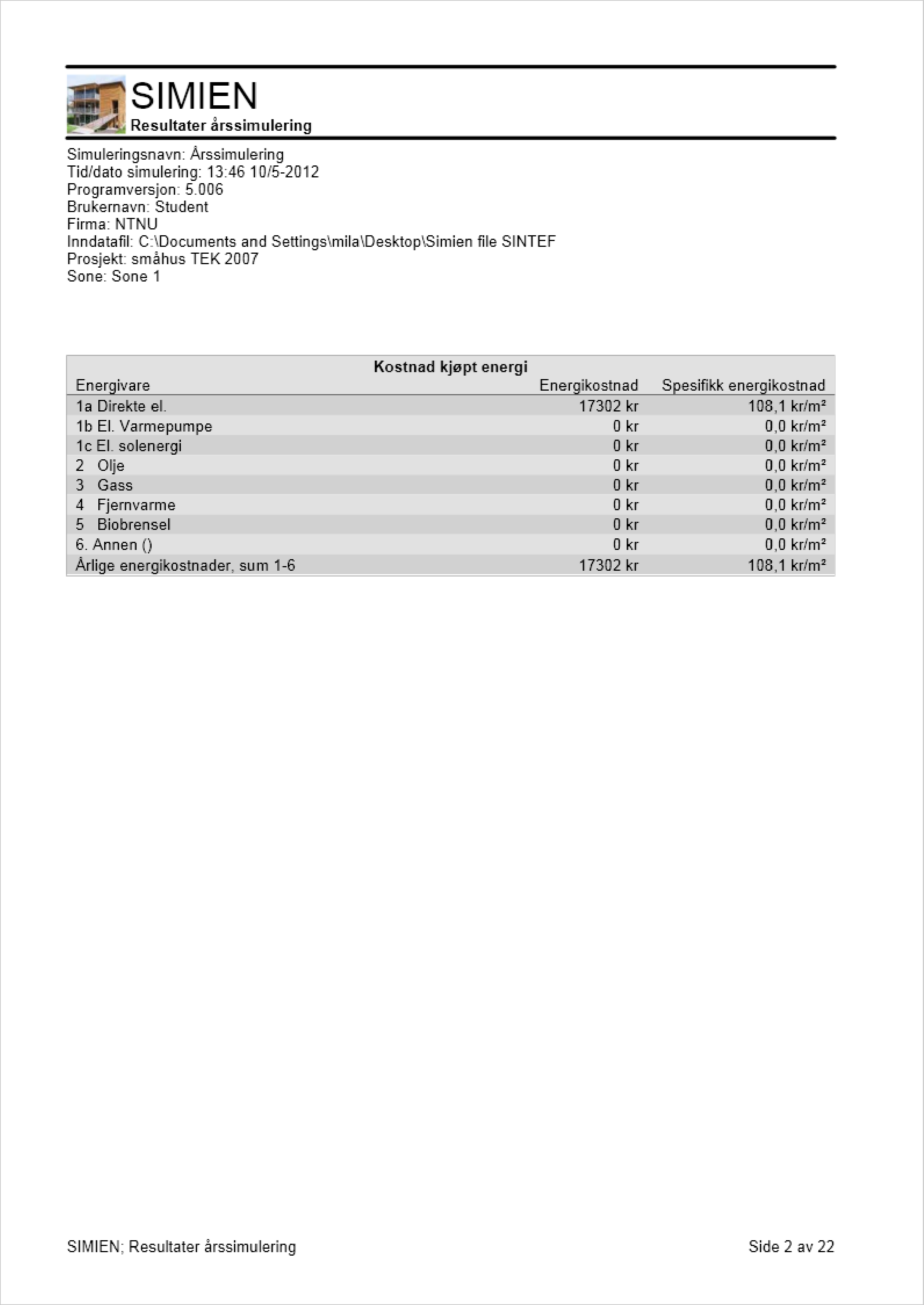
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	21628 kWh	135,2 kWh/m²
1b El. Varmepumpe	0 kWh	0,0 kWh/m²
1c El. solenergi	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen ()	0 kWh	0,0 kWh/m²
Totalt levert energi, sum 1-6	21628 kWh	135,2 kWh/m²

Årlige utslipp av CO2

Energivare	Utslipp	Spesifikt utslipp
1a Direkte el.	7678 kg	48,0 kg/m²
1b El. Varmepumpe	0 kg	0,0 kg/m²
1c El. solenergi	0 kg	0,0 kg/m²
2 Olje	0 kg	0,0 kg/m²
3 Gass	0 kg	0,0 kg/m²
4 Fjernvarme	0 kg	0,0 kg/m²
5 Biobrensel	0 kg	0,0 kg/m²
6. Annen ()	0 kg	0,0 kg/m²
Totalt utslipp, sum 1-6	7678 kg	48,0 kg/m²

SIMIEN; Resultater årssimulering

Side 1 av 22



SIMIEN

Resultater årssimulering

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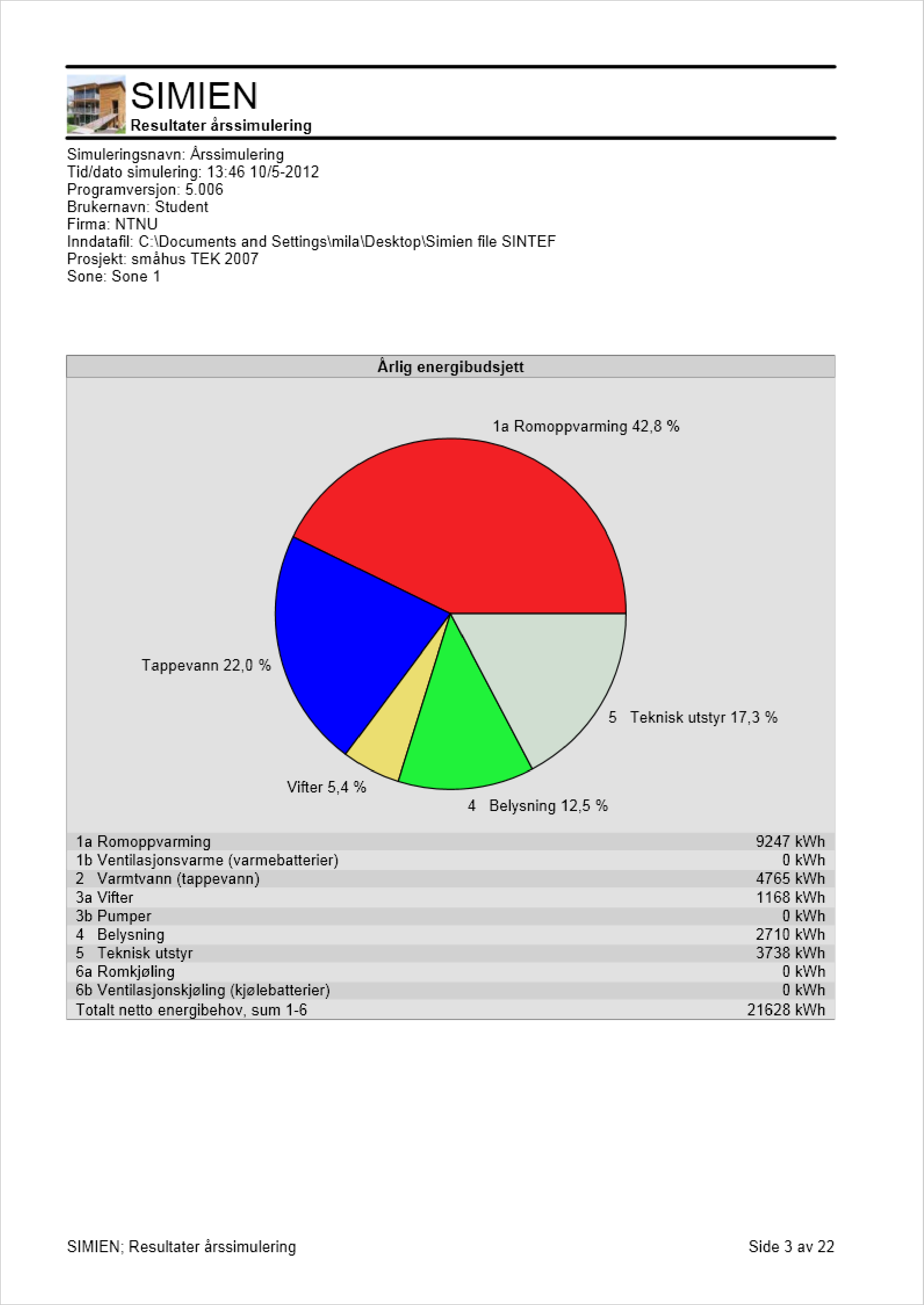
Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Kostnad kjøpt energi

Energivare	Energikostnad	Spesifikk energikostnad
1a Direkte el.	17302 kr	108,1 kr/m²
1b El. Varmepumpe	0 kr	0,0 kr/m²
1c El. solenergi	0 kr	0,0 kr/m²
2 Olje	0 kr	0,0 kr/m²
3 Gass	0 kr	0,0 kr/m²
4 Fjernvarme	0 kr	0,0 kr/m²
5 Biobrensel	0 kr	0,0 kr/m²
6. Annen ()	0 kr	0,0 kr/m²
Årlige energikostnader, sum 1-6	17302 kr	108,1 kr/m²



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
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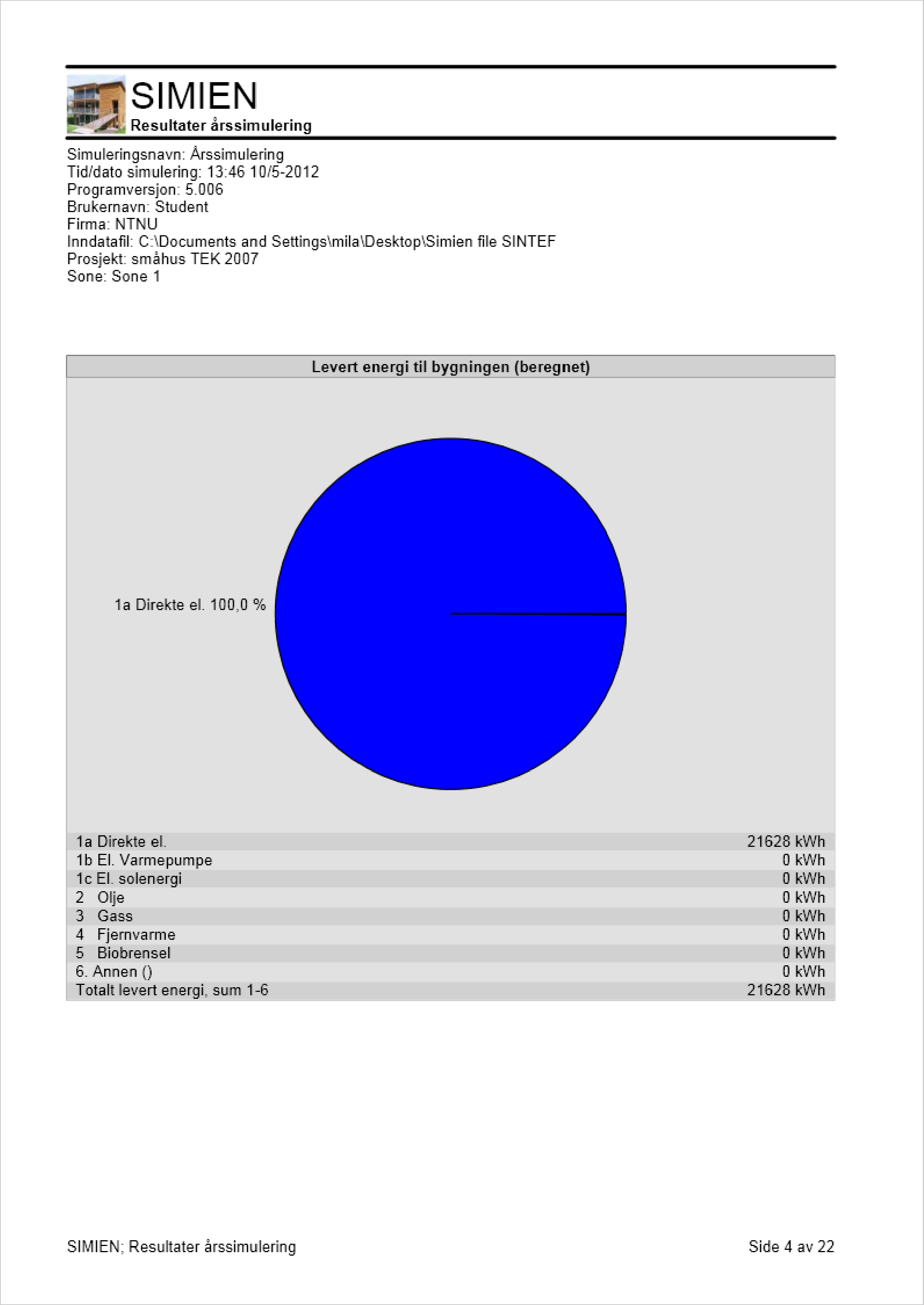
Prosjekt: småhus TEK 2007
Sone: Sone 1

Årlig energibudsjett

1a Romoppvarming	9247 kWh
1b Ventilasjonsvarme (varmebatterier)	0 kWh
2 Varmtvann (tappevann)	4765 kWh
3a Vifter	1168 kWh
3b Pumper	0 kWh
4 Belysning	2710 kWh
5 Teknisk utstyr	3738 kWh
6a Romkjøling	0 kWh
6b Ventilasjonskjøling (kjølebatterier)	0 kWh
Totalt netto energibehov, sum 1-6	21628 kWh



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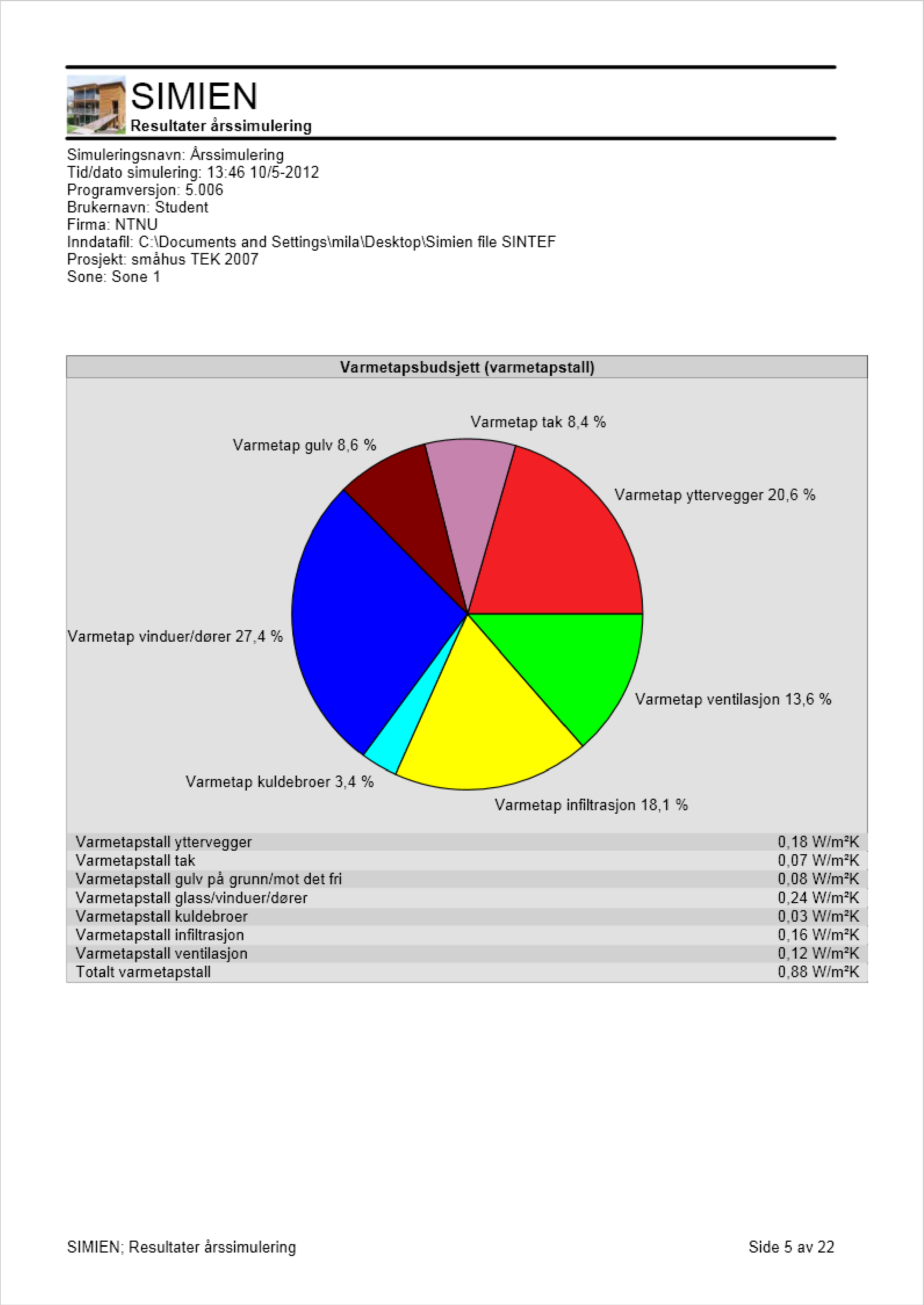
Sone: Sone 1

Levert energi til bygningen (beregnet)

1a Direkte el.	21628 kWh
1b El. Varmepumpe	0 kWh
1c El. solenergi	0 kWh
2 Olje	0 kWh
3 Gass	0 kWh
4 Fjernvarme	0 kWh
5 Biobrensel	0 kWh
6. Annen ()	0 kWh
Totalt levert energi, sum 1-6	21628 kWh



SIMIEN

Resultater årssimulering

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Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
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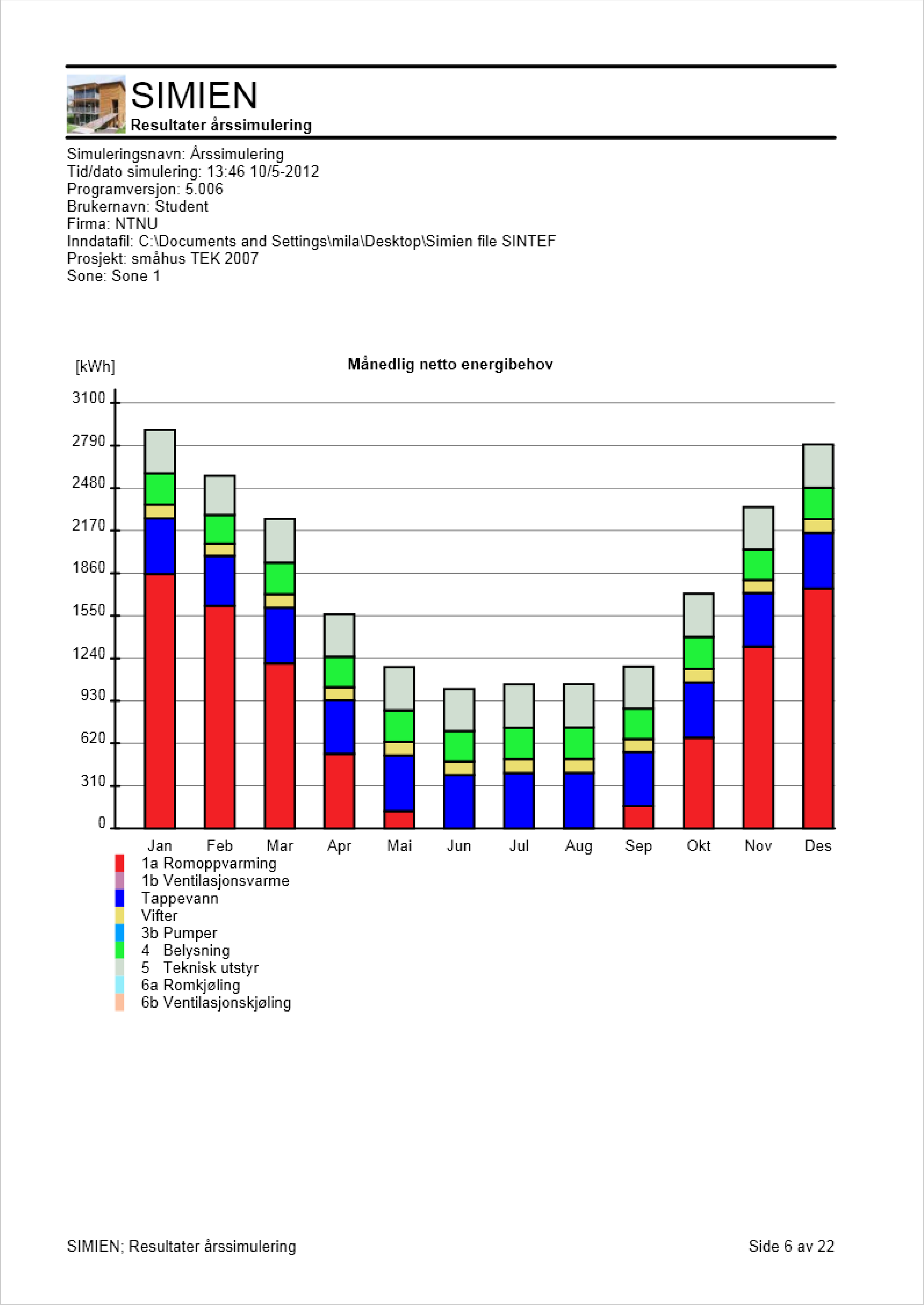
Prosjekt: småhus TEK 2007
Sone: Sone 1

Varmetapsbudsjett (varmetapstall)

Varmetapstall yttervegger	0,18 W/m²K
Varmetapstall tak	0,07 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,08 W/m²K
Varmetapstall glass/vinduer/dører	0,24 W/m²K
Varmetapstall kuldebroer	0,03 W/m²K
Varmetapstall infiltrasjon	0,16 W/m²K
Varmetapstall ventilasjon	0,12 W/m²K
Totalt varmetapstall	0,88 W/m²K



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Resultater årssimulering

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Brukernavn: Student
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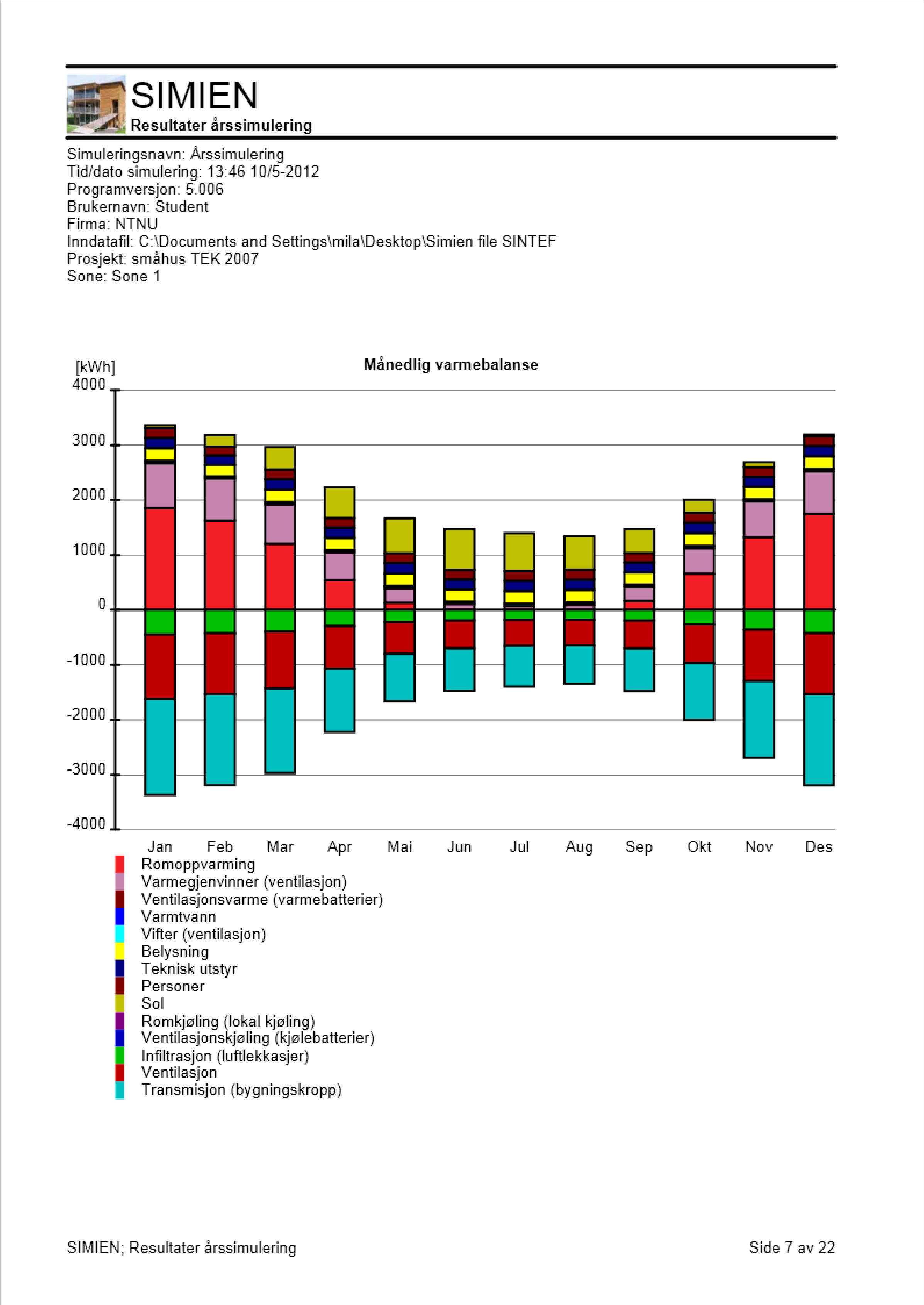
Prosjekt: småhus TEK 2007
Sone: Sone 1

Månedlig netto energibehov



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Resultater årssimulering

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Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Månedlig varmebalanse

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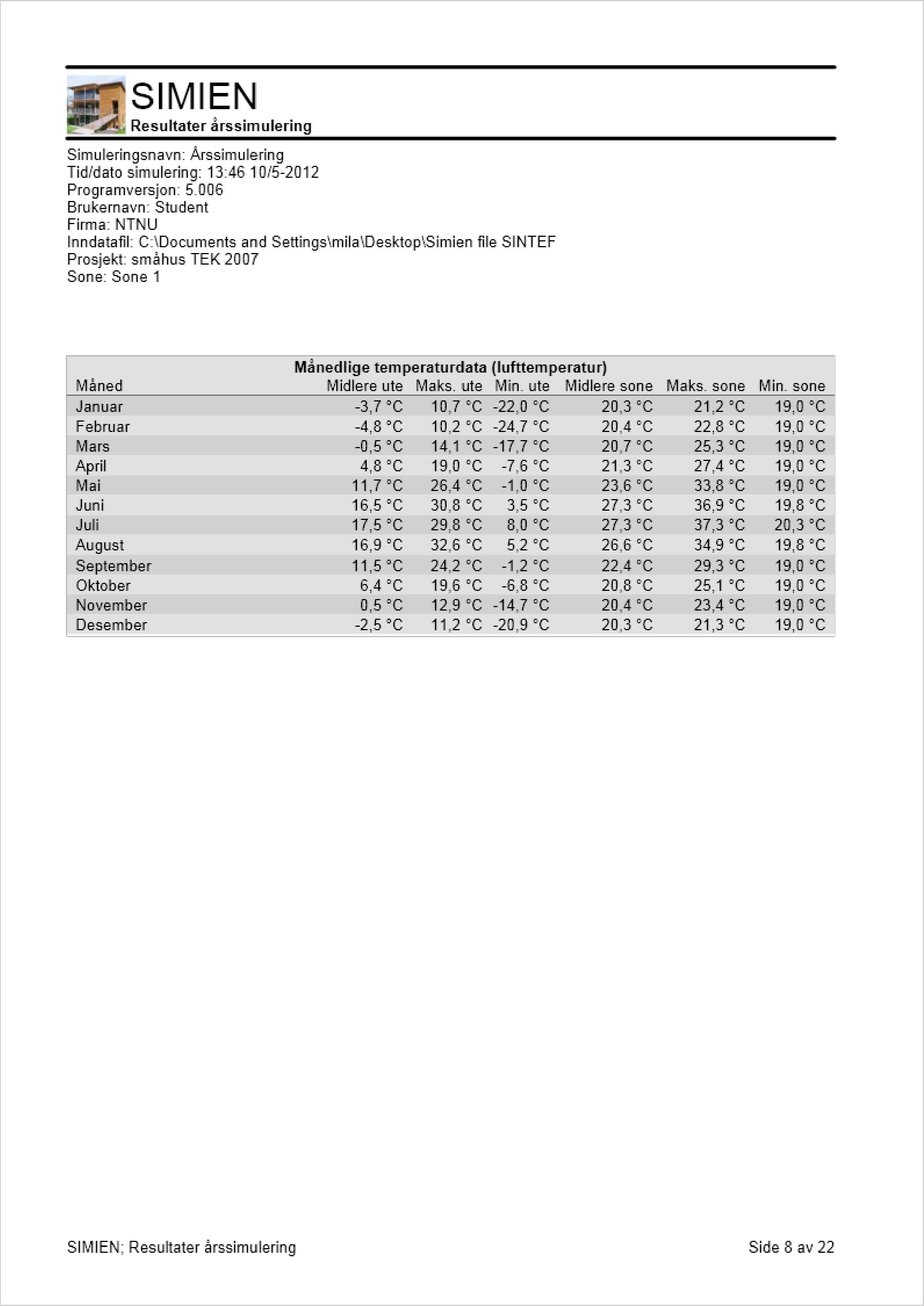


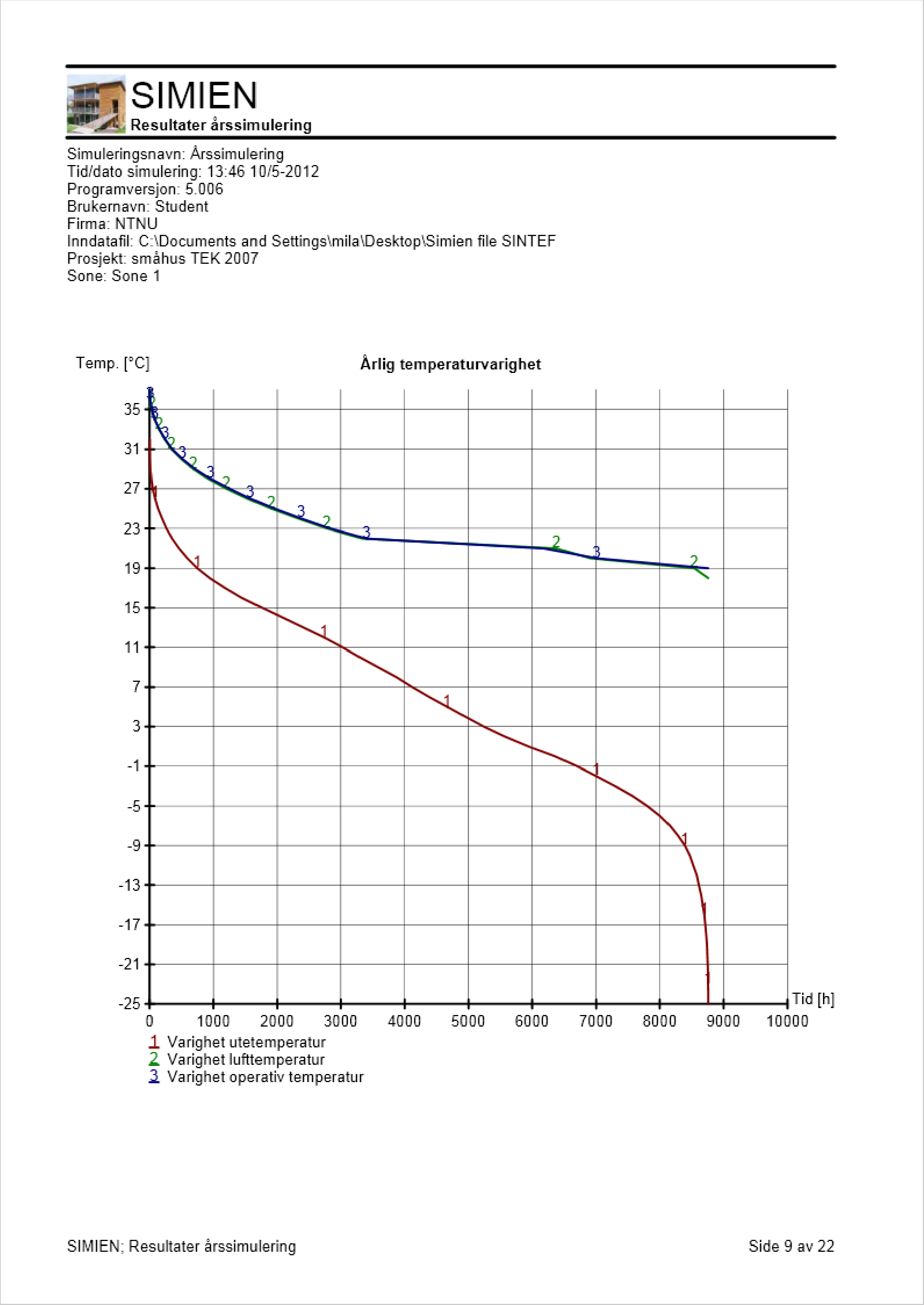
SIMIEN

Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Månedlige temperaturdata (lufttemperatur)

Måned	Midlere ute	Maks. ute	Min. ute	Midlere sone	Maks. sone	Min. sone
Januar	-3,7 °C	10,7 °C	-22,0 °C	20,3 °C	21,2 °C	19,0 °C
Februar	-4,8 °C	10,2 °C	-24,7 °C	20,4 °C	22,8 °C	19,0 °C
Mars	-0,5 °C	14,1 °C	-17,7 °C	20,7 °C	25,3 °C	19,0 °C
April	4,8 °C	19,0 °C	-7,6 °C	21,3 °C	27,4 °C	19,0 °C
Mai	11,7 °C	26,4 °C	-1,0 °C	23,6 °C	33,8 °C	19,0 °C
Juni	16,5 °C	30,8 °C	3,5 °C	27,3 °C	36,9 °C	19,8 °C
Juli	17,5 °C	29,8 °C	8,0 °C	27,3 °C	37,3 °C	20,3 °C
August	16,9 °C	32,6 °C	5,2 °C	26,6 °C	34,9 °C	19,8 °C
September	11,5 °C	24,2 °C	-1,2 °C	22,4 °C	29,3 °C	19,0 °C
Oktober	6,4 °C	19,6 °C	-6,8 °C	20,8 °C	25,1 °C	19,0 °C
November	0,5 °C	12,9 °C	-14,7 °C	20,4 °C	23,4 °C	19,0 °C
Desember	-2,5 °C	11,2 °C	-20,9 °C	20,3 °C	21,3 °C	19,0 °C



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Resultater årssimulering

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Prosjekt: småhus TEK 2007
Sone: Sone 1

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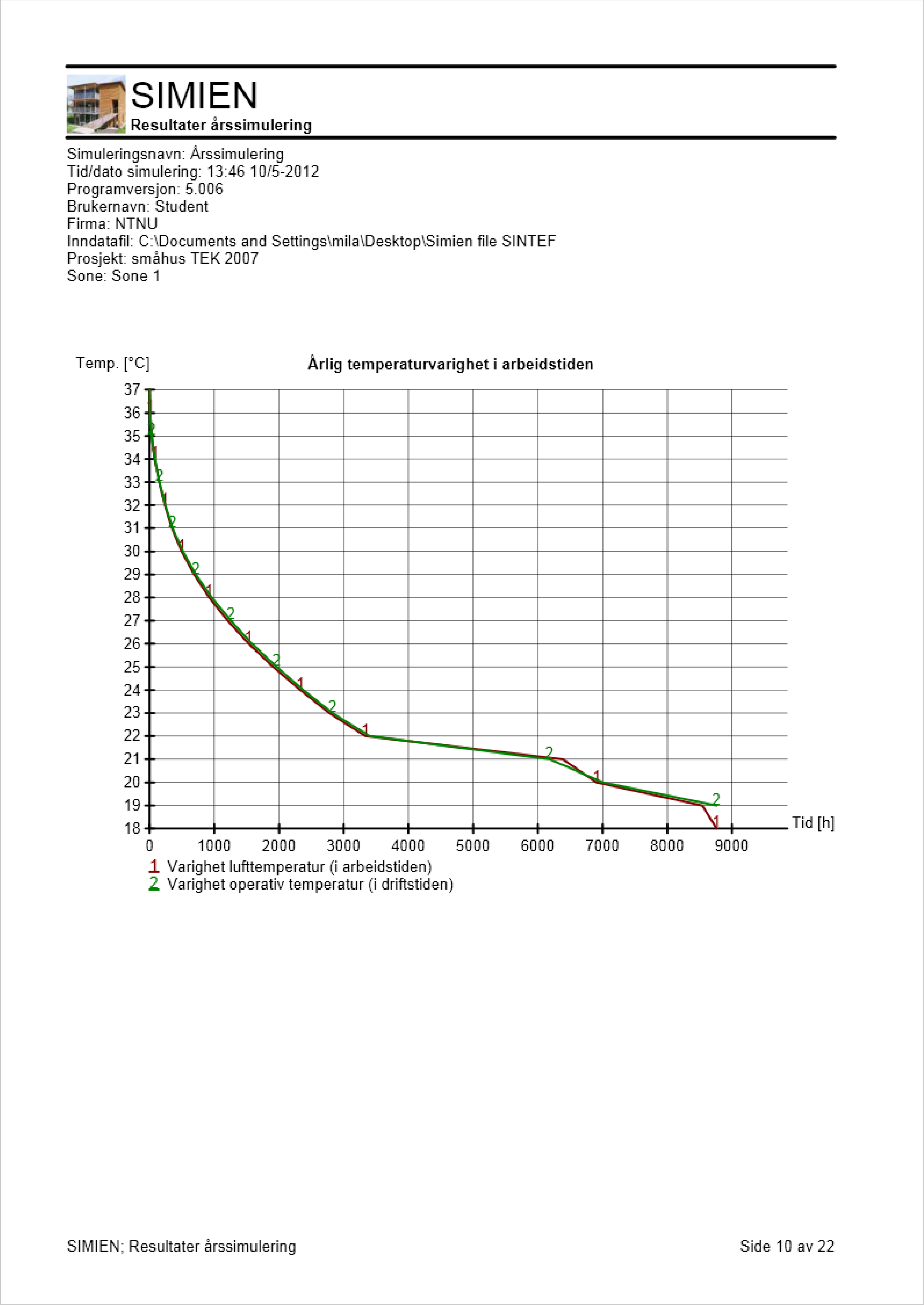
Side 9 av 22



SIMIEN

Resultater årssimulering

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Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Årlig temperaturvarighet i arbeidstiden

SIMIEN; Resultater årssimulering

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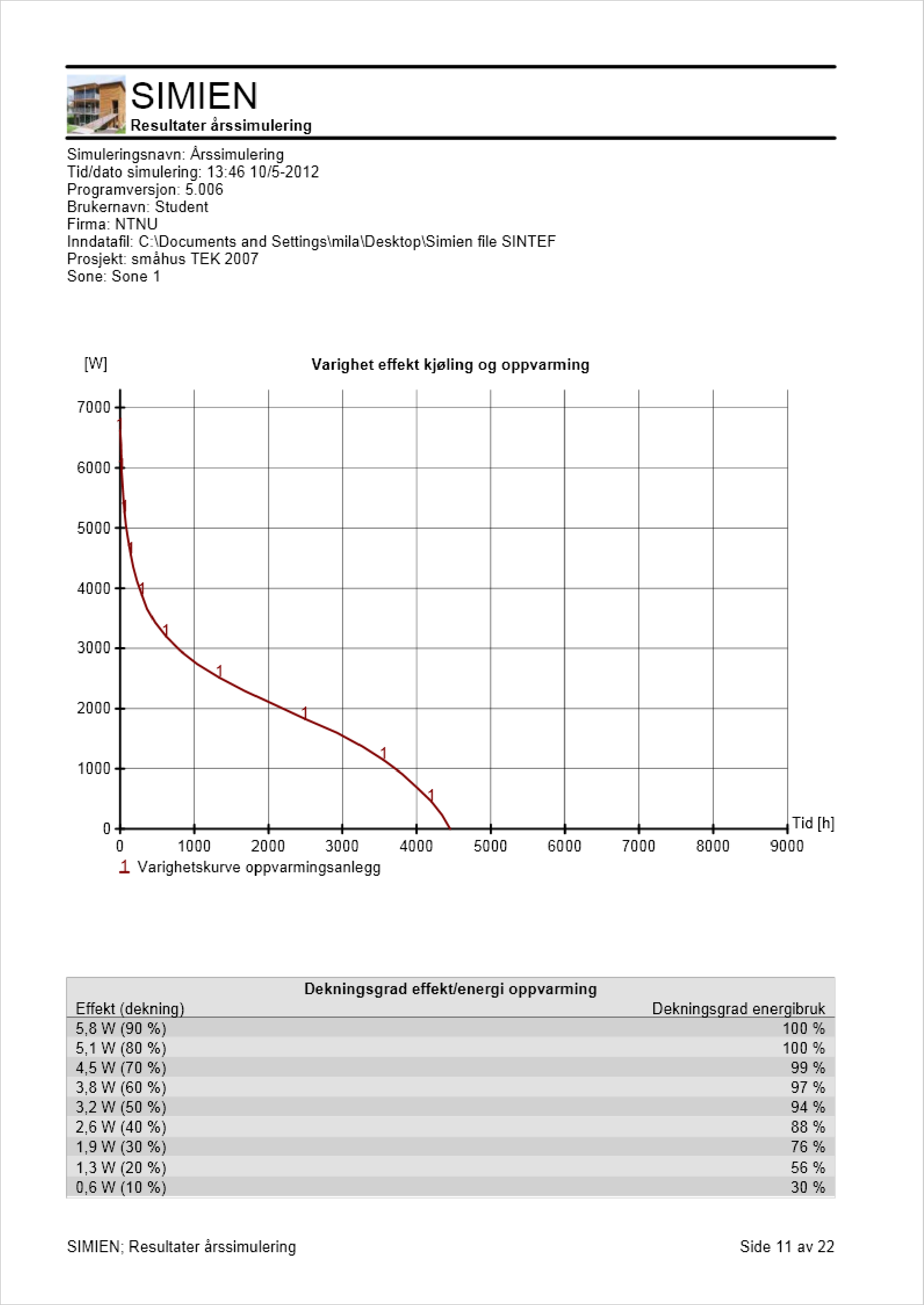

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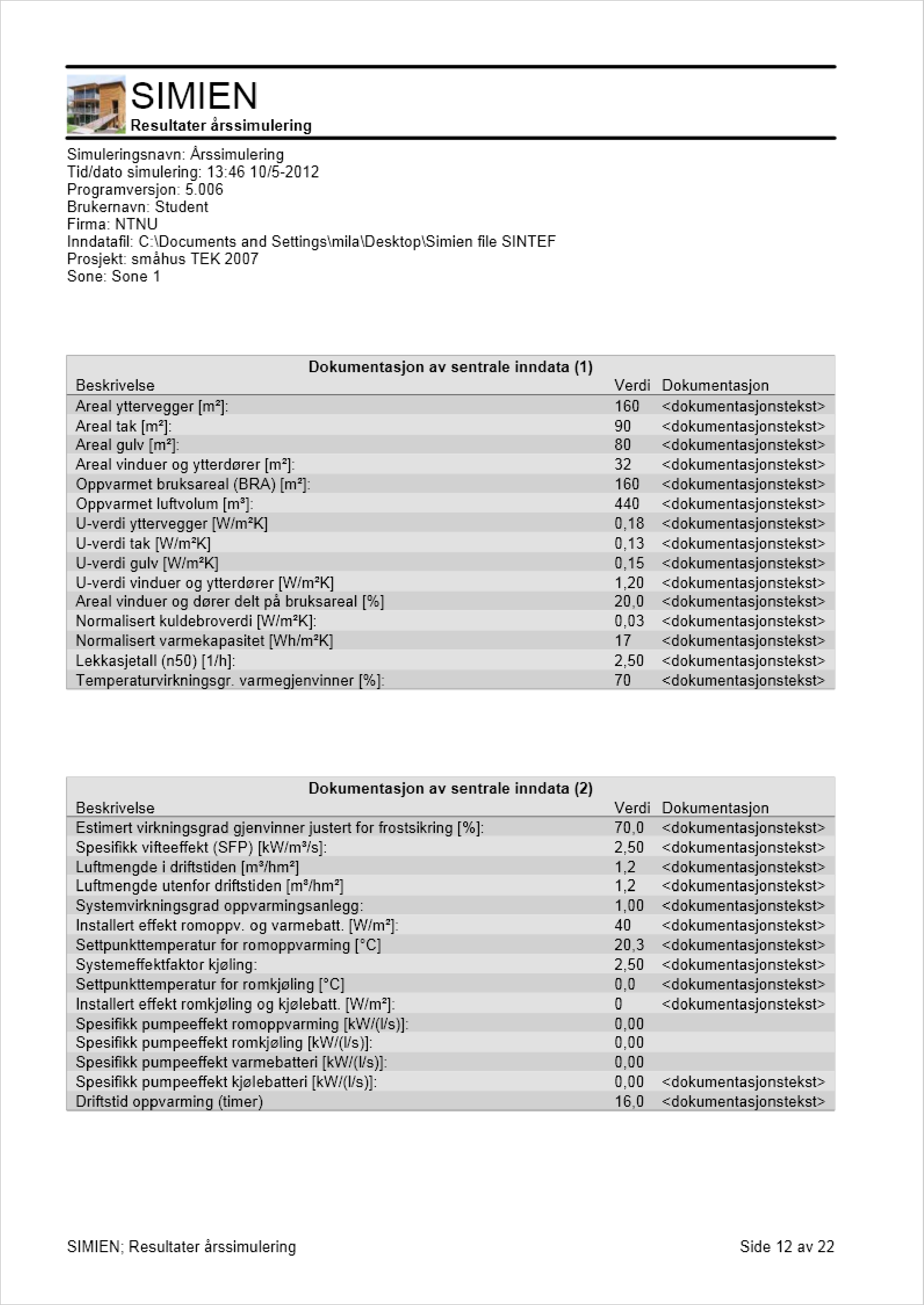
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Varighet effekt kjøling og oppvarming

Dekningsgrad effekt/energi oppvarming

Effekt (dekning)	Dekningsgrad energibruk
5,8 W (90 %)	100 %
5,1 W (80 %)	100 %
4,5 W (70 %)	99 %
3,8 W (60 %)	97 %
3,2 W (50 %)	94 %
2,6 W (40 %)	88 %
1,9 W (30 %)	76 %
1,3 W (20 %)	56 %
0,6 W (10 %)	30 %



SIMIEN
Resultater årssimulering

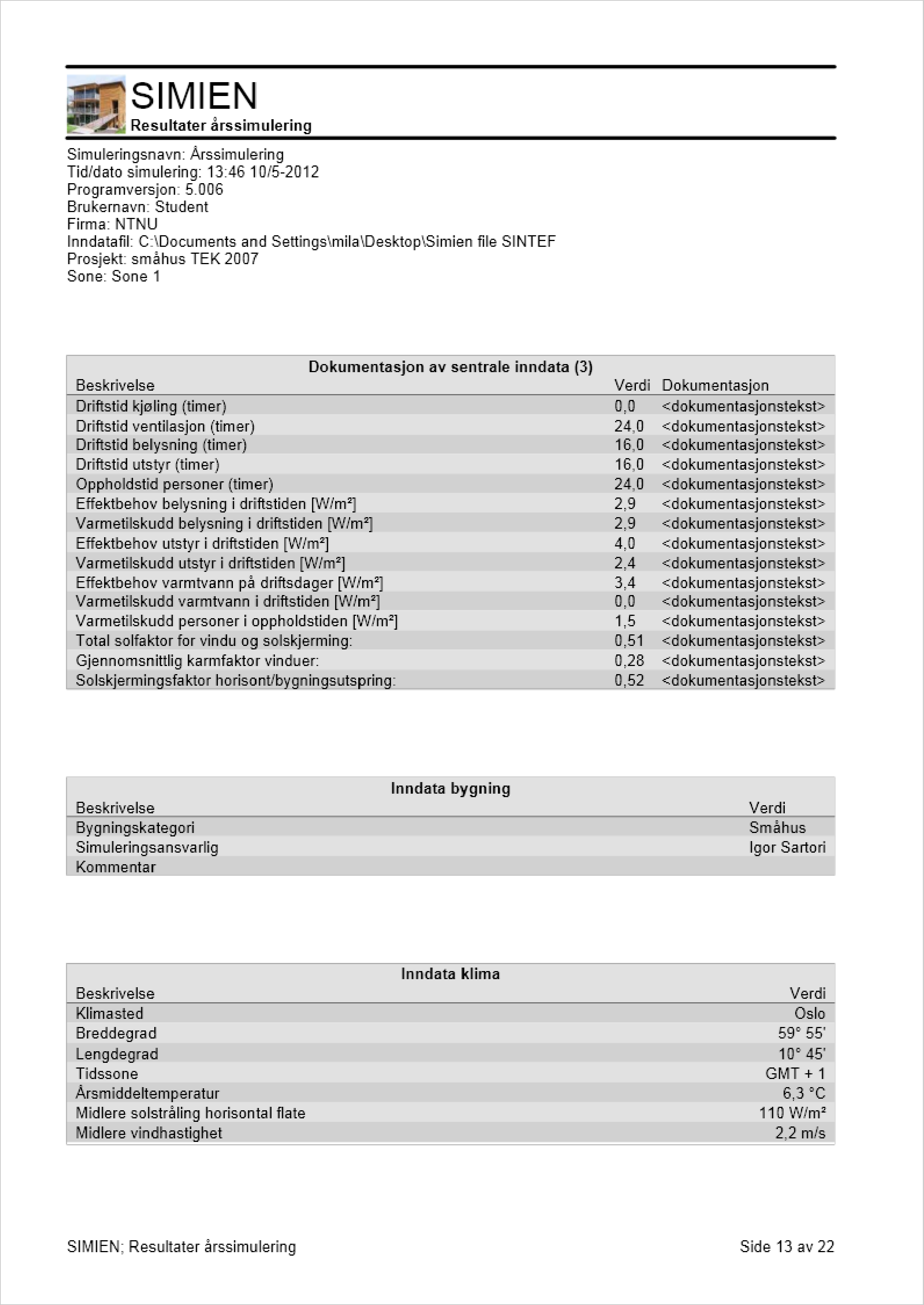
Simuleringsnavn: Årssimulering
Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Dokumentasjon av sentrale inndata (1)

Beskrivelse	Verdi	Dokumentasjon
Areal yttervegger [m^2]:	160	<dokumentasjonstekst>
Areal tak [m^2]:	90	<dokumentasjonstekst>
Areal gulv [m^2]:	80	<dokumentasjonstekst>
Areal vinduer og ytterdører [m^2]:	32	<dokumentasjonstekst>
Oppvarmet bruksareal (BRA) [m^2]:	160	<dokumentasjonstekst>
Oppvarmet luftvolum [m^3]:	440	<dokumentasjonstekst>
U-verdi yttervegger [W/m^{2}K]	0,18	<dokumentasjonstekst>
U-verdi tak [W/m^{2}K]	0,13	<dokumentasjonstekst>
U-verdi gulv [W/m^{2}K]	0,15	<dokumentasjonstekst>
U-verdi vinduer og ytterdører [W/m^{2}K]	1,20	<dokumentasjonstekst>
Areal vinduer og dører delt på bruksareal [%]	20,0	<dokumentasjonstekst>
Normalisert kuldebroverdi [W/m^{2}K]:	0,03	<dokumentasjonstekst>
Normalisert varmekapasitet [Wh/m^{2}K]	17	<dokumentasjonstekst>
Lekkasjetall (n50) [1/h]:	2,50	<dokumentasjonstekst>
Temperaturvirkningsgr. varmegjenvinner [%]:	70	<dokumentasjonstekst>

Dokumentasjon av sentrale inndata (2)

Beskrivelse	Verdi	Dokumentasjon
Estimert virkningsgrad gjenvinner justert for frostsikring [%]:	70,0	<dokumentasjonstekst>
Spesifikk vifteeffekt (SFP) [kW/m^3/s]:	2,50	<dokumentasjonstekst>
Luftmengde i driftstiden [m^3/hm^2]	1,2	<dokumentasjonstekst>
Luftmengde utenfor driftstiden [m^3/hm^2]	1,2	<dokumentasjonstekst>
Systemvirkningsgrad oppvarmingsanlegg:	1,00	<dokumentasjonstekst>
Installert effekt romoppv. og varmebatt. [W/m^2]:	40	<dokumentasjonstekst>
Settpunkttemperatur for romoppvarming [°C]	20,3	<dokumentasjonstekst>
Systemeffektfaktor kjøling:	2,50	<dokumentasjonstekst>
Settpunkttemperatur for romkjøling [°C]	0,0	<dokumentasjonstekst>
Installert effekt romkjøling og kjølebatt. [W/m^2]:	0	<dokumentasjonstekst>
Spesifikk pumpeeffekt romoppvarming [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt romkjøling [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt varmebatteri [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt kjølebatteri [kW/(l/s)]:	0,00	<dokumentasjonstekst>
Driftstid oppvarming (timer)	16,0	<dokumentasjonstekst>



SIMIEN

Resultater årssimulering

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Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Dokumentasjon av sentrale inndata (3)

Beskrivelse	Verdi	Dokumentasjon
Driftstid kjøling (timer)	0,0	<dokumentasjonstekst>
Driftstid ventilasjon (timer)	24,0	<dokumentasjonstekst>
Driftstid belysning (timer)	16,0	<dokumentasjonstekst>
Driftstid utstyr (timer)	16,0	<dokumentasjonstekst>
Oppholdstid personer (timer)	24,0	<dokumentasjonstekst>
Effektbehov belysning i driftstiden [W/m²]	2,9	<dokumentasjonstekst>
Varmetilskudd belysning i driftstiden [W/m²]	2,9	<dokumentasjonstekst>
Effektbehov utstyr i driftstiden [W/m²]	4,0	<dokumentasjonstekst>
Varmetilskudd utstyr i driftstiden [W/m²]	2,4	<dokumentasjonstekst>
Effektbehov varmtvann på driftsdager [W/m²]	3,4	<dokumentasjonstekst>
Varmetilskudd varmtvann i driftstiden [W/m²]	0,0	<dokumentasjonstekst>
Varmetilskudd personer i oppholdstiden [W/m²]	1,5	<dokumentasjonstekst>
Total solfaktor for vindu og solskjerming:	0,51	<dokumentasjonstekst>
Gjennomsnittlig karmfaktor vinduer:	0,28	<dokumentasjonstekst>
Solskjermingsfaktor horisont/bygningsutspring:	0,52	<dokumentasjonstekst>

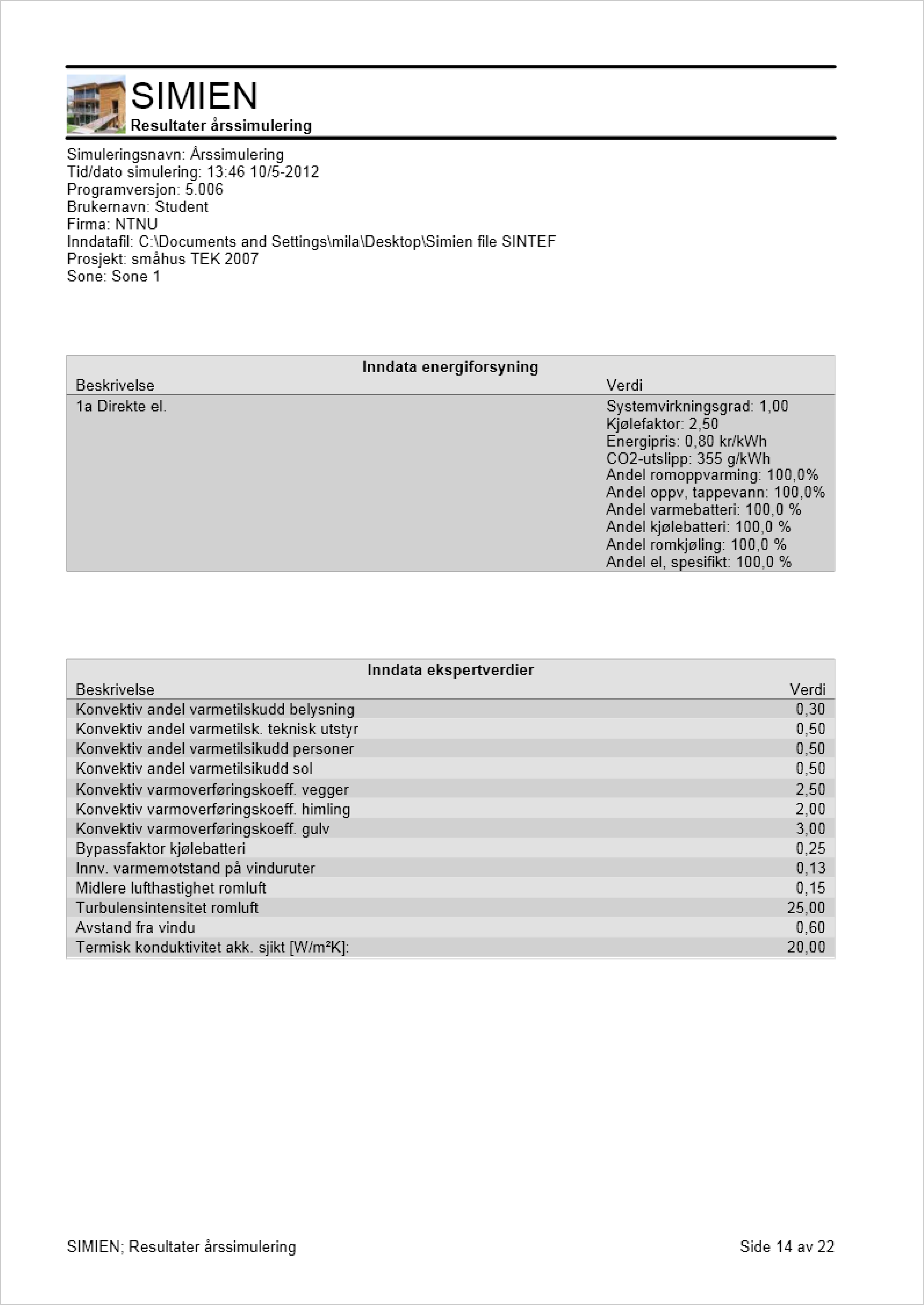
Inndata bygning

Beskrivelse	Verdi
Bygningskategori	Småhus
Simuleringsansvarlig	Igor Sartori
Kommentar	

Inndata klima

Beskrivelse	Verdi
Klimasted	Oslo
Breddegrad	59° 55'
Lengdegrad	10° 45'
Tidssone	GMT + 1
Årsmiddeltemperatur	6,3 °C
Midlere solstråling horisontal flate	110 W/m²
Midlere vindhastighet	2,2 m/s

SIMIEN; Resultater årssimulering Side 13 av 22



SIMIEN

Resultater årssimulering

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Prosjekt: småhus TEK 2007
Sone: Sone 1

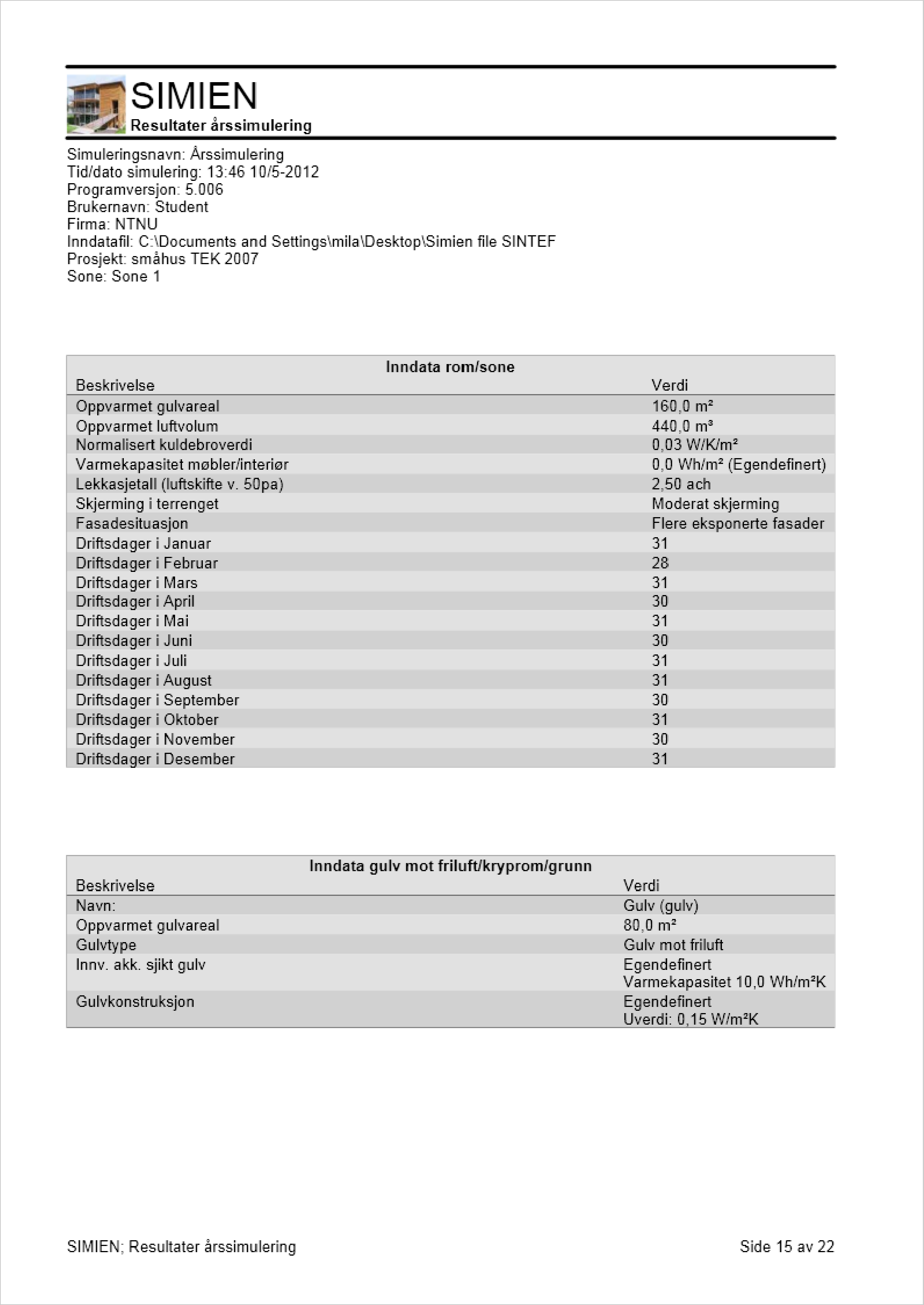
Inndata energiforsyning

Beskrivelse	Verdi
1a Direkte el.	Systemvirkningsgrad: 1,00 Kjølefaktor: 2,50 Energipris: 0,80 kr/kWh CO2-utslipp: 355 g/kWh Andel romoppvarming: 100,0% Andel oppv, tappevann: 100,0% Andel varmebatteri: 100,0 % Andel kjølebatteri: 100,0 % Andel romkjøling: 100,0 % Andel el, spesifikt: 100,0 %

Inndata ekspertverdier

Beskrivelse	Verdi
Konvektiv andel varmetilskudd belysning	0,30
Konvektiv andel varmetilsk. teknisk utstyr	0,50
Konvektiv andel varmetilsikudd personer	0,50
Konvektiv andel varmetilsikudd sol	0,50
Konvektiv varmoverføringskoeff. vegger	2,50
Konvektiv varmoverføringskoeff. himling	2,00
Konvektiv varmoverføringskoeff. gulv	3,00
Bypassfaktor kjølebatteri	0,25
Innv. varmemotstand på vinduruter	0,13
Midlere lufthastighet romluft	0,15
Turbulensintensitet romluft	25,00
Avstand fra vindu	0,60
Termisk konduktivitet akk. sjikt [W/m²K]:	20,00

SIMIEN; Resultater årssimulering Side 14 av 22



SIMIEN

Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 13:46 10/5-2012
Programversjon: 5.006
Brukernavn: Student
Firma: NTNU
Inndatafil: C:\Documents and Settings\mila\Desktop\Simien file SINTEF
Prosjekt: småhus TEK 2007
Sone: Sone 1

Inndata rom/sone

Beskrivelse	Verdi
Oppvarmet gulvareal	160,0 m²
Oppvarmet luftvolum	440,0 m³
Normalisert kuldebroverdi	0,03 W/K/m²
Varmekapasitet møbler/interiør	0,0 Wh/m² (Egendefinert)
Lekkasjetall (luftskifte v. 50pa)	2,50 ach
Skjerming i terrenget	Moderat skjerming
Fasadesituasjon	Flere eksponerte fasader
Driftsdager i Januar	31
Driftsdager i Februar	28
Driftsdager i Mars	31
Driftsdager i April	30
Driftsdager i Mai	31
Driftsdager i Juni	30
Driftsdager i Juli	31
Driftsdager i August	31
Driftsdager i September	30
Driftsdager i Oktober	31
Driftsdager i November	30
Driftsdager i Desember	31

Inndata gulv mot friluft/kryprom/grunn

Beskrivelse	Verdi
Navn:	Gulv (gulv)
Oppvarmet gulvareal	80,0 m²
Gulvtype	Gulv mot friluft
Innv. akk. sjikt gulv	Egendefinert Varmekapasitet 10,0 Wh/m²K
Gulvkonstruksjon	Egendefinert Uverdi: 0,15 W/m²K

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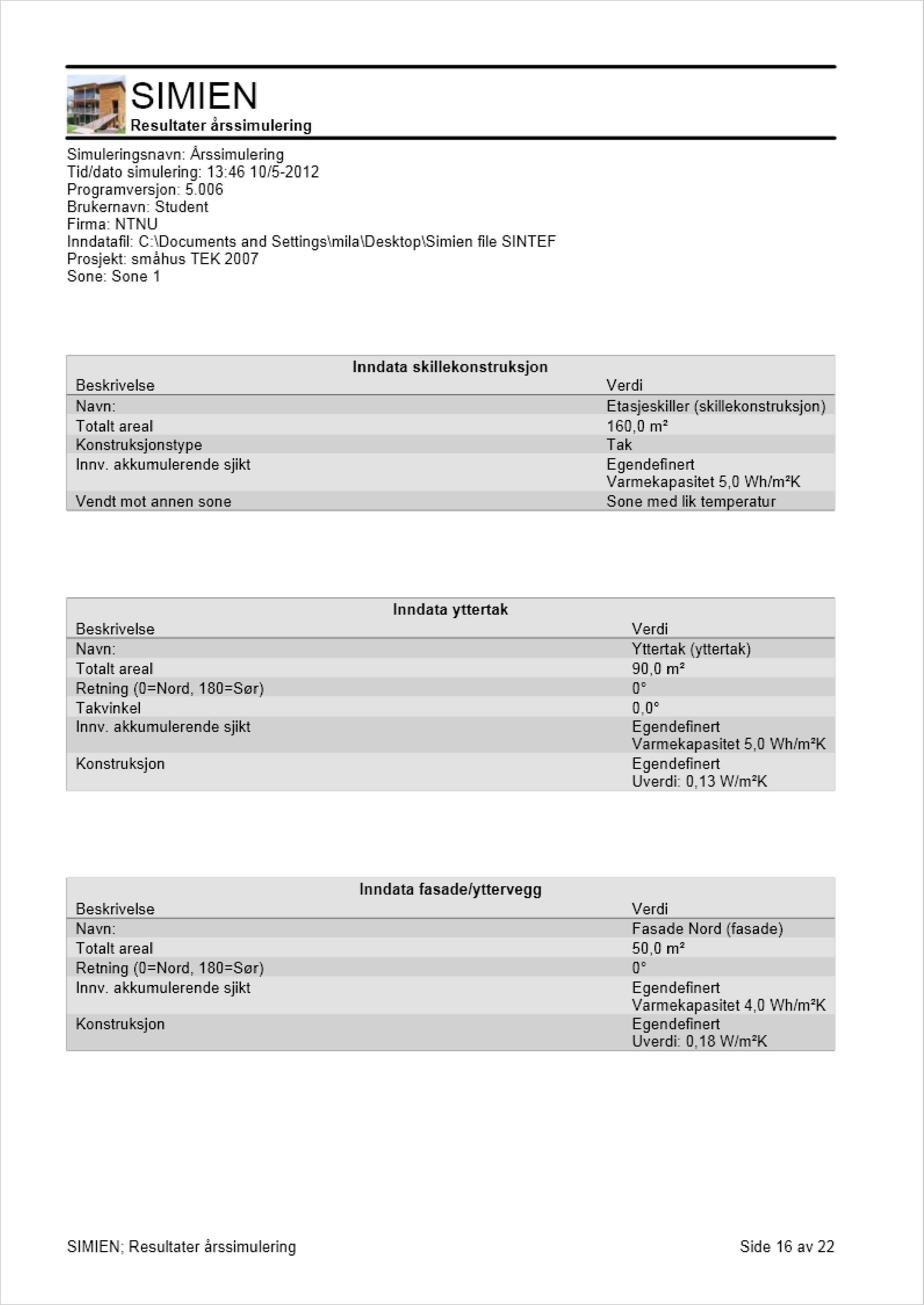

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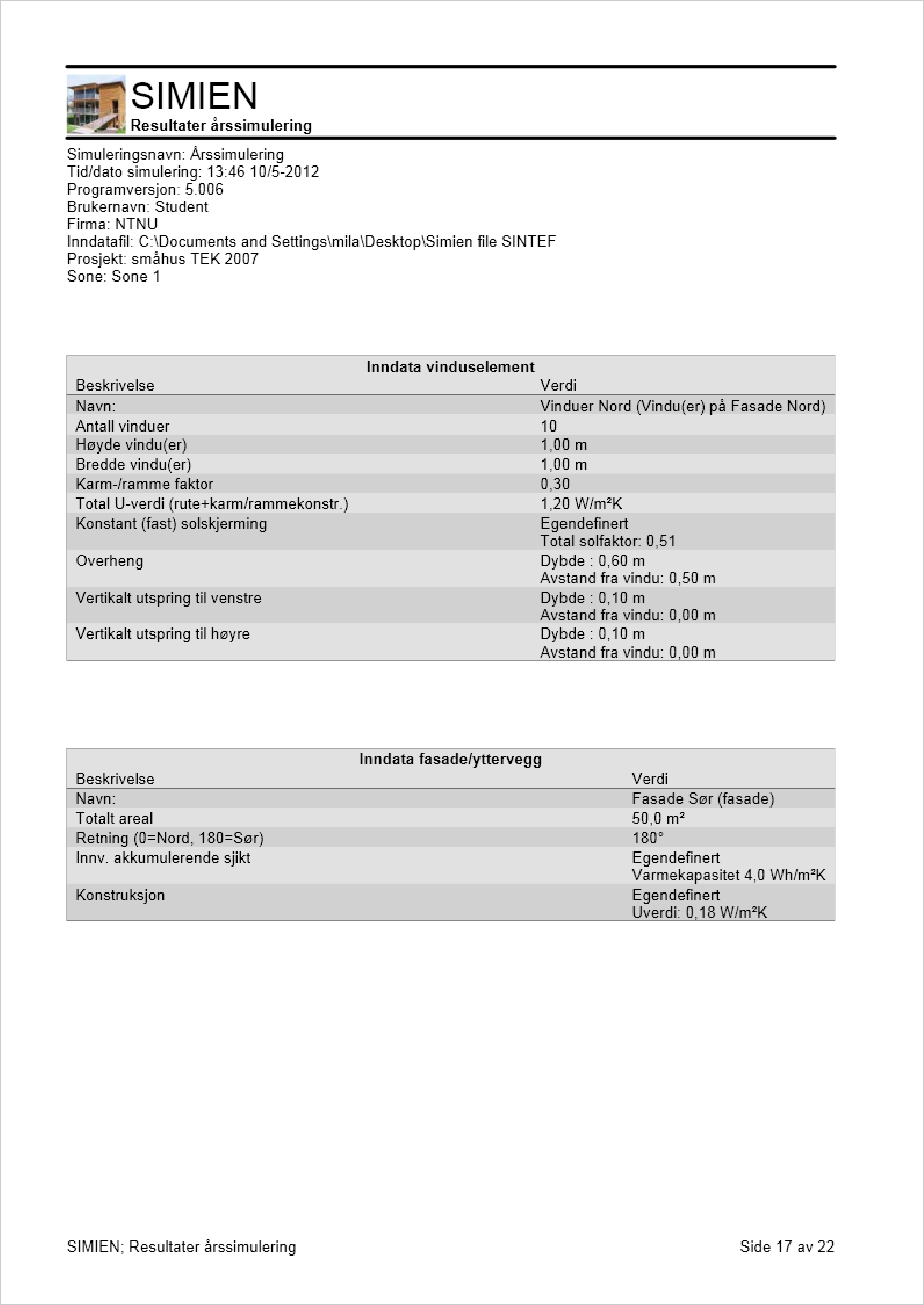
Inndata skillekonstruksjon	
Beskrivelse	Verdi
Navn:	Etasjeskiller (skillekonstruksjon)
Totalt areal	160,0 m²
Konstruksjonstype	Tak
Innv. akkumulerende sjikt	Egendefinert Varmekapasitet 5,0 Wh/m²K
Vendt mot annen sone	Sone med lik temperatur

Inndata yttertak	
Beskrivelse	Verdi
Navn:	Yttertak (yttertak)
Totalt areal	90,0 m²
Retning (0=Nord, 180=Sør)	0°
Takvinkel	0,0°
Innv. akkumulerende sjikt	Egendefinert Varmekapasitet 5,0 Wh/m²K
Konstruksjon	Egendefinert Uverdi: 0,13 W/m²K

Inndata fasade/yttervegg	
Beskrivelse	Verdi
Navn:	Fasade Nord (fasade)
Totalt areal	50,0 m²
Retning (0=Nord, 180=Sør)	0°
Innv. akkumulerende sjikt	Egendefinert Varmekapasitet 4,0 Wh/m²K
Konstruksjon	Egendefinert Uverdi: 0,18 W/m²K



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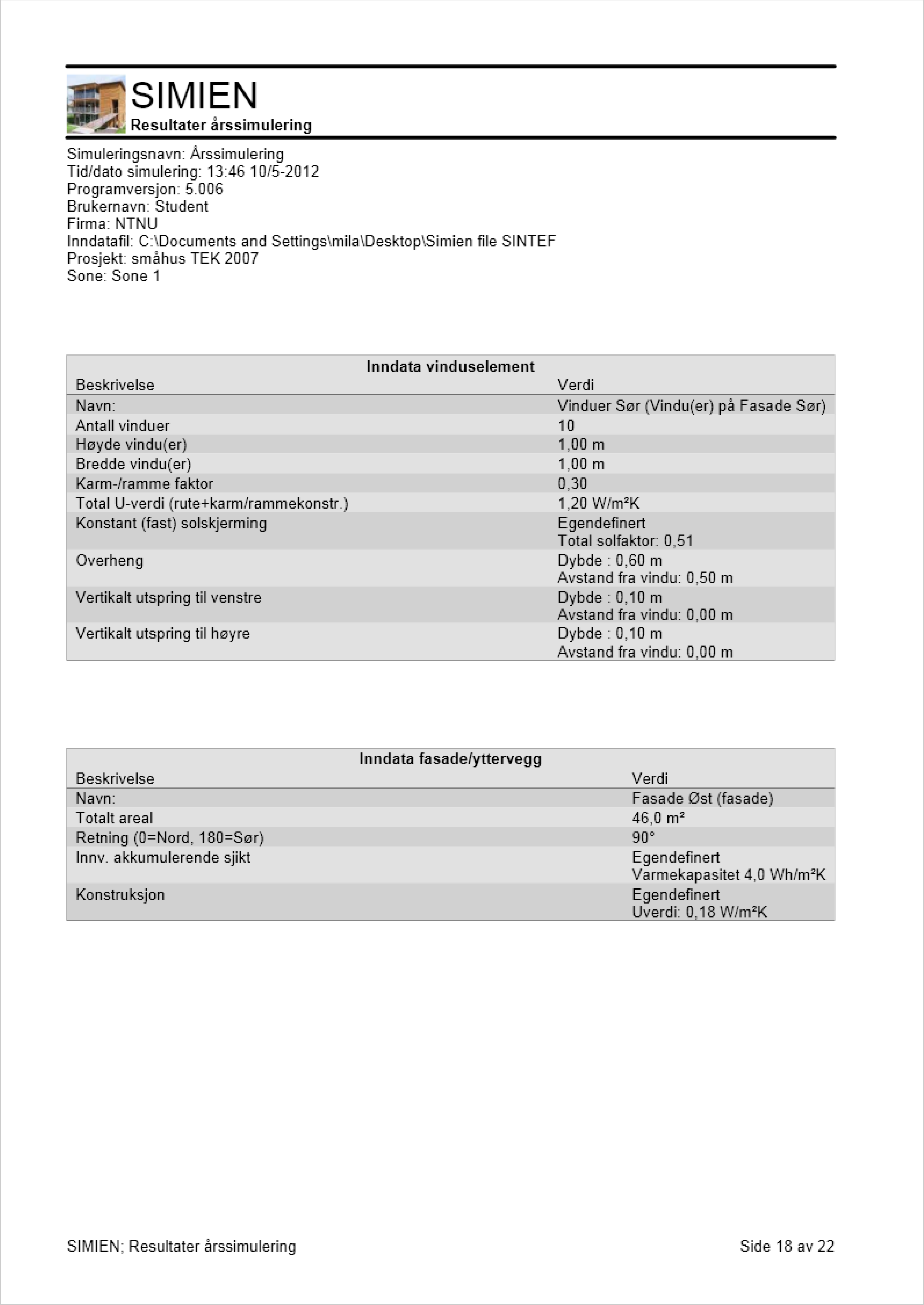
Sone: Sone 1

Inndata vinduselement

Beskrivelse	Verdi
Navn:	Vinduer Nord (Vindu(er) på Fasade Nord)
Antall vinduer	10
Høyde vindu(er)	1,00 m
Bredde vindu(er)	1,00 m
Karm-/ramme faktor	0,30
Total U-verdi (rute+karm/rammekonstr.)	1,20 W/m²K
Konstant (fast) solskjerming	Egendefinert Total solfaktor: 0,51
Overheng	Dybde : 0,60 m Avstand fra vindu: 0,50 m
Vertikalt utspring til venstre	Dybde : 0,10 m Avstand fra vindu: 0,00 m
Vertikalt utspring til høyre	Dybde : 0,10 m Avstand fra vindu: 0,00 m

Inndata fasade/yttervegg

Beskrivelse	Verdi
Navn:	Fasade Sør (fasade)
Totalt areal	50,0 m²
Retning (0=Nord, 180=Sør)	180°
Innv. akkumulerende sjikt	Egendefinert Varmekapasitet 4,0 Wh/m²K
Konstruksjon	Egendefinert Uverdi: 0,18 W/m²K



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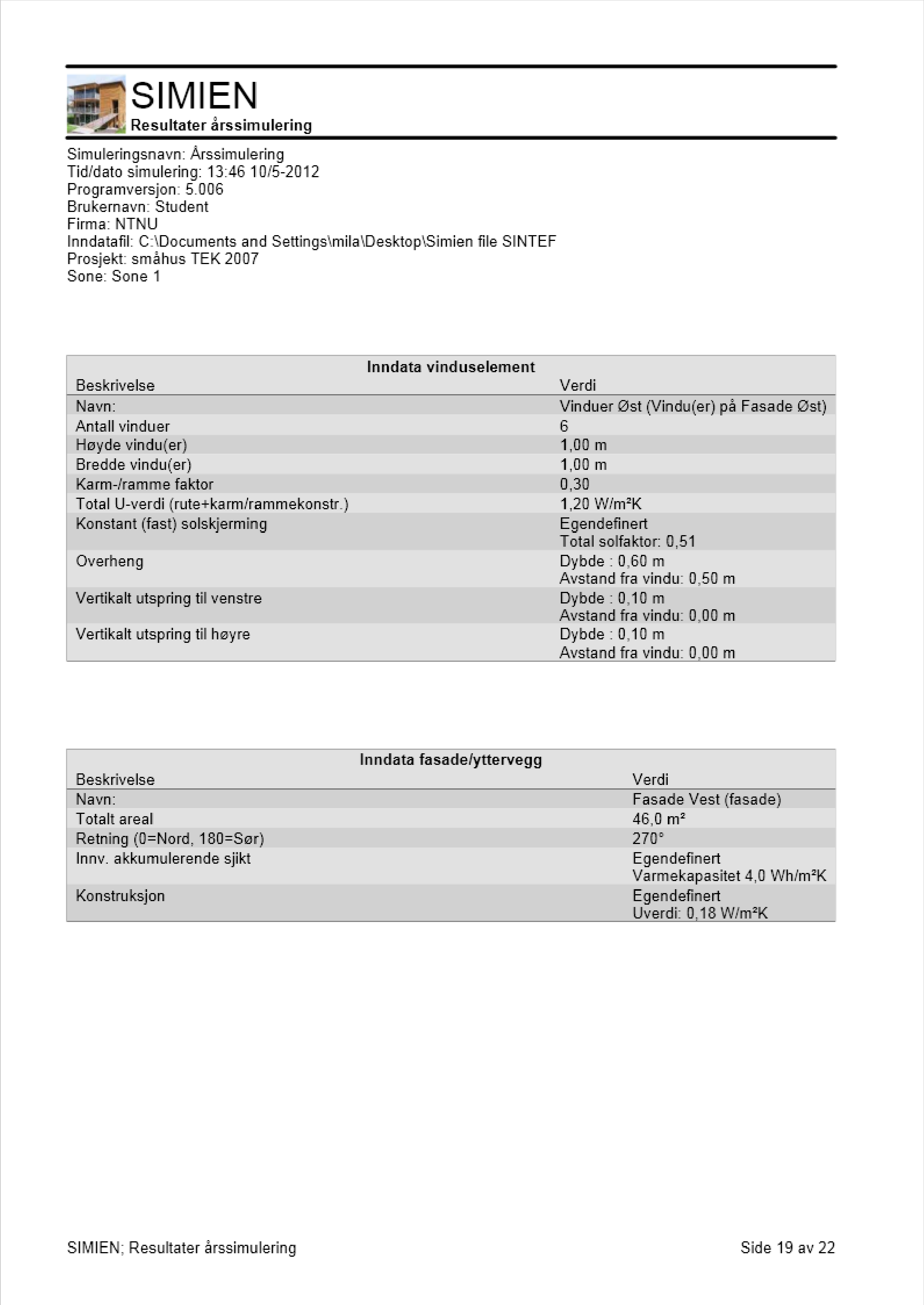
Inndata vinduselement

Beskrivelse	Verdi
Navn:	Vinduer Sør (Vindu(er) på Fasade Sør)
Antall vinduer	10
Høyde vindu(er)	1,00 m
Bredde vindu(er)	1,00 m
Karm-/ramme faktor	0,30
Total U-verdi (rute+karm/rammekonstr.)	1,20 W/m²K
Konstant (fast) solskjerming	Egendefinert Total solfaktor: 0,51
Overheng	Dybde : 0,60 m Avstand fra vindu: 0,50 m
Vertikalt utspring til venstre	Dybde : 0,10 m Avstand fra vindu: 0,00 m
Vertikalt utspring til høyre	Dybde : 0,10 m Avstand fra vindu: 0,00 m

Inndata fasade/yttervegg

Beskrivelse	Verdi
Navn:	Fasade Øst (fasade)
Totalt areal	46,0 m²
Retning (0=Nord, 180=Sør)	90°
Innv. akkumulerende sjikt	Egendefinert Varmekapasitet 4,0 Wh/m²K
Konstruksjon	Egendefinert Uverdi: 0,18 W/m²K



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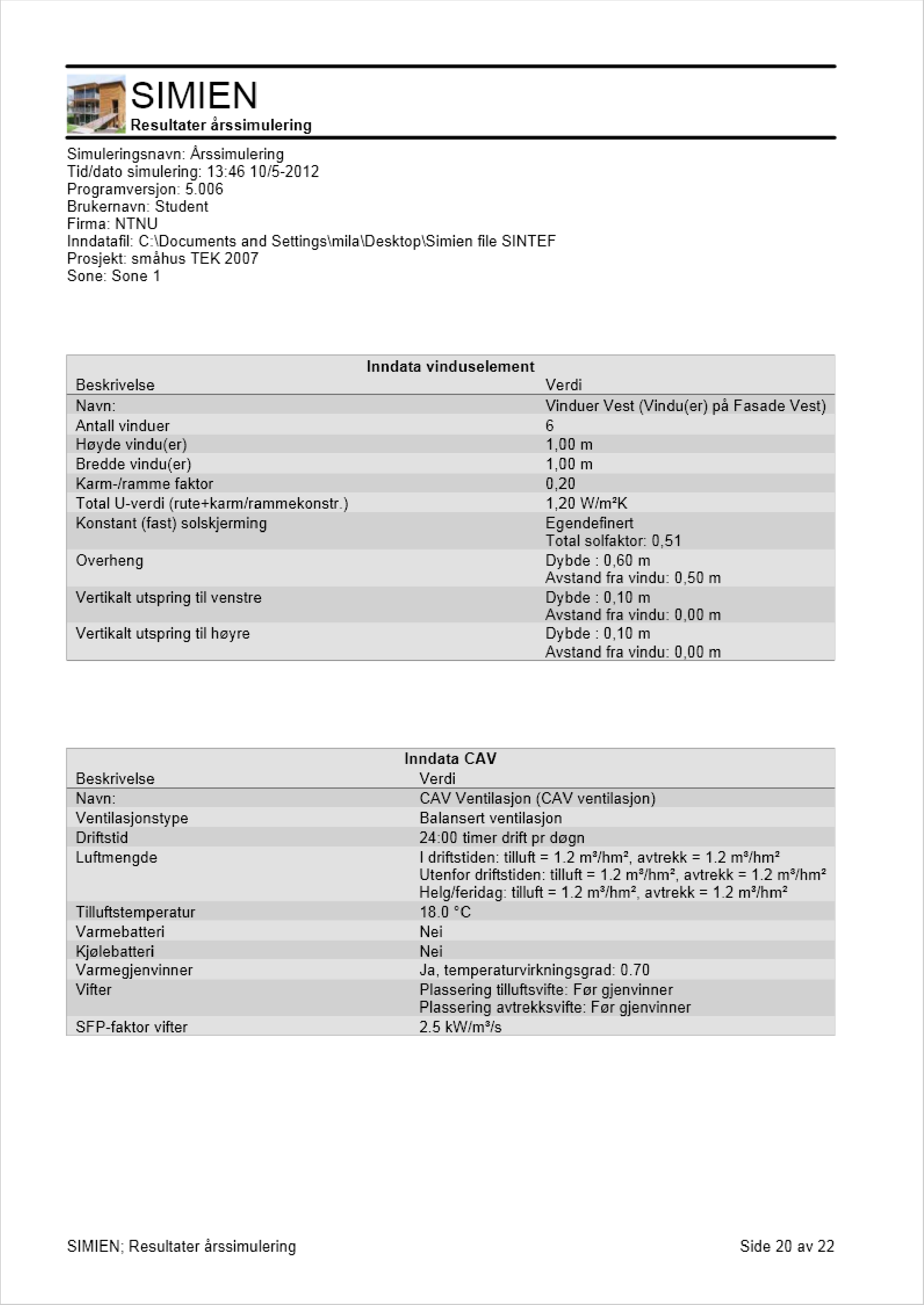
Sone: Sone 1

Inndata vinduselement

Beskrivelse	Verdi
Navn:	Vinduer Øst (Vindu(er) på Fasade Øst)
Antall vinduer	6
Høyde vindu(er)	1,00 m
Bredde vindu(er)	1,00 m
Karm-/ramme faktor	0,30
Total U-verdi (rute+karm/rammekonstr.)	1,20 W/m²K
Konstant (fast) solskjerming	Egendefinert Total solfaktor: 0,51
Overheng	Dybde : 0,60 m Avstand fra vindu: 0,50 m
Vertikalt utspring til venstre	Dybde : 0,10 m Avstand fra vindu: 0,00 m
Vertikalt utspring til høyre	Dybde : 0,10 m Avstand fra vindu: 0,00 m

Inndata fasade/yttervegg

Beskrivelse	Verdi
Navn:	Fasade Vest (fasade)
Totalt areal	46,0 m²
Retning (0=Nord, 180=Sør)	270°
Innv. akkumulerende sjikt	Egendefinert Varmekapasitet 4,0 Wh/m²K
Konstruksjon	Egendefinert Uverdi: 0,18 W/m²K



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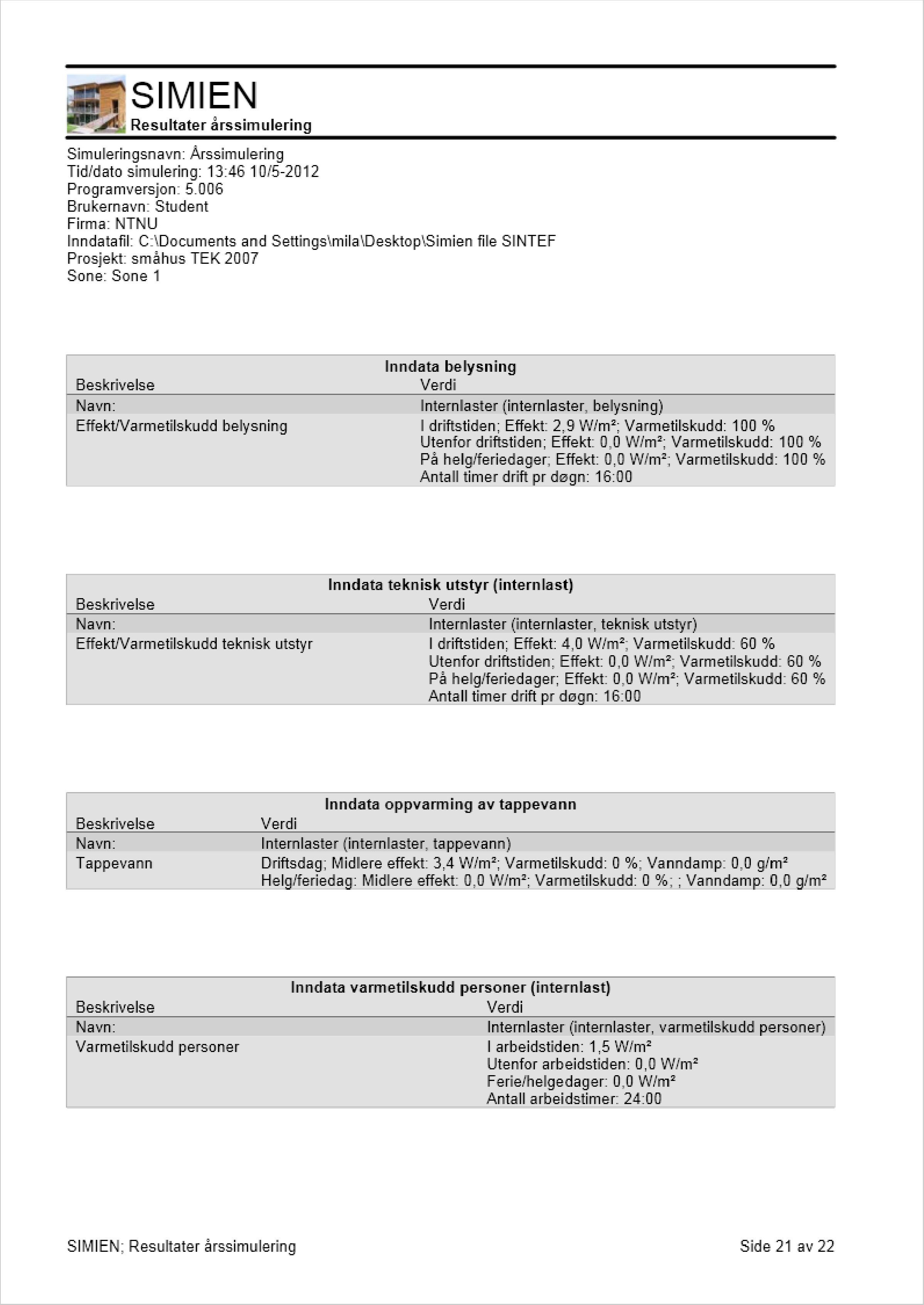
Sone: Sone 1

Inndata vinduselement

Beskrivelse	Verdi
Navn:	Vinduer Vest (Vindu(er) på Fasade Vest)
Antall vinduer	6
Høyde vindu(er)	1,00 m
Bredde vindu(er)	1,00 m
Karm-/ramme faktor	0,20
Total U-verdi (rute+karm/rammekonstr.)	1,20 W/m^{2}K
Konstant (fast) solskjerming	Egendefinert Total solfaktor: 0,51
Overheng	Dybde : 0,60 m Avstand fra vindu: 0,50 m
Vertikalt utspring til venstre	Dybde : 0,10 m Avstand fra vindu: 0,00 m
Vertikalt utspring til høyre	Dybde : 0,10 m Avstand fra vindu: 0,00 m

Inndata CAV

Beskrivelse	Verdi
Navn:	CAV Ventilasjon (CAV ventilasjon)
Ventilasjonstype	Balansert ventilasjon
Driftstid	24:00 timer drift pr døgn
Luftmengde	I driftstiden: tilluft = 1.2 m^3/hm^2, avtrekk = 1.2 m^3/hm^2 Utenfor driftstiden: tilluft = 1.2 m^3/hm^2, avtrekk = 1.2 m^3/hm^2 Helg/feridag: tilluft = 1.2 m^3/hm^2, avtrekk = 1.2 m^3/hm^2
Tilluftstemperatur	18.0 °C
Varmebatteri	Nei
Kjølebatteri	Nei
Varmegjenvinner	Ja, temperaturvirkningsgrad: 0.70
Vifter	Plassering tilluftsvifte: Før gjenvinner Plassering avtrekksvifte: Før gjenvinner
SFP-faktor vifter	2.5 kW/m^3/s



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Inndata belysning

Beskrivelse	Verdi
Navn:	Internlaster (internlaster, belysning)
Effekt/Varmetilskudd belysning	I driftstiden; Effekt: 2,9 W/m²; Varmetilskudd: 100 % Utenfor driftstiden; Effekt: 0,0 W/m²; Varmetilskudd: 100 % På helg/feriedager; Effekt: 0,0 W/m²; Varmetilskudd: 100 % Antall timer drift pr døgn: 16:00

Inndata teknisk utstyr (internlast)

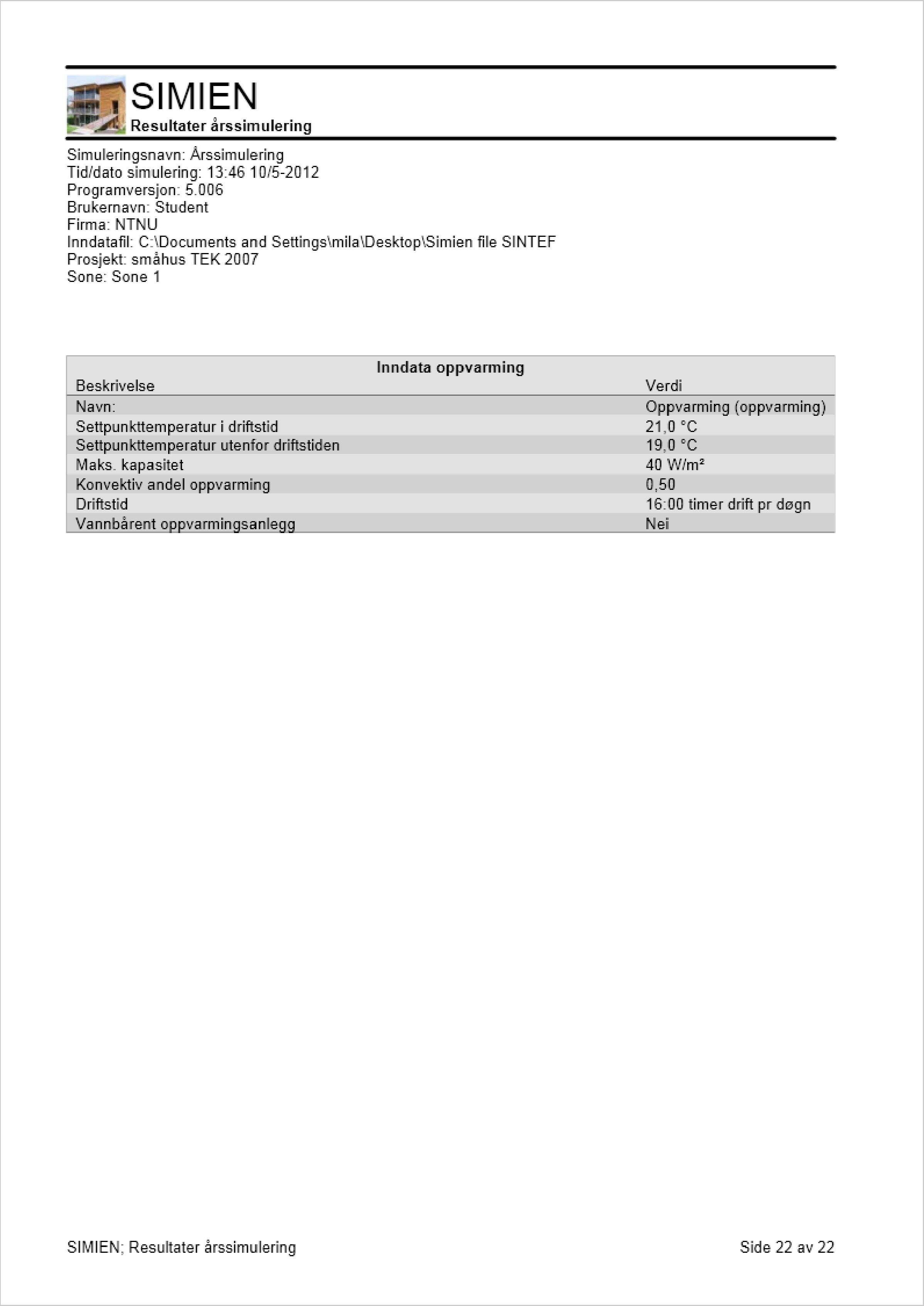
Beskrivelse	Verdi
Navn:	Internlaster (internlaster, teknisk utstyr)
Effekt/Varmetilskudd teknisk utstyr	I driftstiden; Effekt: 4,0 W/m²; Varmetilskudd: 60 % Utenfor driftstiden; Effekt: 0,0 W/m²; Varmetilskudd: 60 % På helg/feriedager; Effekt: 0,0 W/m²; Varmetilskudd: 60 % Antall timer drift pr døgn: 16:00

Inndata oppvarming av tappevann

Beskrivelse	Verdi
Navn:	Internlaster (internlaster, tappevann)
Tappevann	Driftsdag; Midlere effekt: 3,4 W/m²; Varmetilskudd: 0 %; Vanndamp: 0,0 g/m² Helg/feriedag: Midlere effekt: 0,0 W/m²; Varmetilskudd: 0 %; ; Vanndamp: 0,0 g/m²

Inndata varmetilskudd personer (internlast)

Beskrivelse	Verdi
Navn:	Internlaster (internlaster, varmetilskudd personer)
Varmetilskudd personer	I arbeidstiden: 1,5 W/m² Utenfor arbeidstiden: 0,0 W/m² Ferie/helgedager: 0,0 W/m² Antall arbeidstimer: 24:00



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Inndata oppvarming

Beskrivelse	Verdi
Navn:	Oppvarming (oppvarming)
Settpunkttemperatur i driftstid	21,0 °C
Settpunkttemperatur utenfor driftstiden	19,0 °C
Maks. kapasitet	40 W/m²
Konvektiv andel oppvarming	0,50
Driftstid	16:00 timer drift pr døgn
Vannbårent oppvarmingsanlegg	Nei

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