VALIDATION OF TEKNOsim 5

Verification against different standards and building energy simulation tools

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Lund University

Lund University, with eight faculties and a number of research centers and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programmes and 2 300 subject courses offered by 63 departments.

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The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

The growth of building energy simulation tools has provided users with a variety of alternatives to model and simulate buildings. The algorithms used in each building energy simulation software are different and range from simple to highly complex. TEKNOsim is a simple design tool based on analytical and empirical algorithms. It is used for calculating building thermal loads and simulating indoor thermal climate. A new version of TEKNOsim has been released (Version 5) with a new interface and feature enhancements.

This thesis aims to validate the algorithms used in TEKNOsim 5. The objective is to demonstrate the accuracy and reliability of the results that TEKNOsim 5 provides. The thesis is divided into three main parts: 1) Qualitative analysis of features of TEKNOsim 5 through a survey performed on a sample of users, 2) Analytical verification against three European Standards through verification procedures proposed by these Standards, and 3) Comparative verification against several building energy simulation tools through the Building Energy Simulation Test (BESTEST) cases.

The survey results indicate that TEKNOsim 5 is perceived as an efficient tool with good functionality and a user-friendly interface with easy navigation. The survey results also suggest some future developments to make TEKNOsim more attractive to users. The analytical and comparative verifications indicate that TEKNOsim is a reliable and accurate tool for the evaluation of indoor thermal climate. It provides an accurate estimation of the peak sensible cooling load with relatively short model setup and simulation time. The peak heating loads are somewhat overestimated by TEKNOsim, but no more than 12 % compared to other simulation tools. A possible change, to reduce the deviation of TEKNOsim 5 results in comparison to other simulation tools, is to modify the way outdoor climate is defined and setup.

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Definitions, Abbreviations, and Acronyms

ACH: *Air Changes per Hour*.

Analytical verification tests: Tests that include analytical solutions for specific heat transfer processes under prescribed model conditions.

ANSI, *American National Standards Institute*: The Institute oversees the creation, promulgation and use of thousands of norms and guidelines that directly impact businesses in nearly every sector: from acoustical devices to construction equipment, from dairy and livestock production to energy distribution, and much more. ANSI is also actively engaged in accreditation - assessing the competence of organizations determining conformance to Standards.

ASHRAE, *American Society of Heating, Refrigerating and Air-Conditioning Engineers*: A global society advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry. It was founded in 1894.

BESTEST, *Building Energy Simulation Test*.

BS, *British Standard*.

BSI, *British Standard Institution*: The business Standards company that helps organizations all over the world to create Standards, certifications, and verifications.

CAD, *Computer Aided Drafting*: The use of computer systems to aid in the creation, modification, analysis, or optimization of a design.

CAV, *Constant Air Volume.*

CEN, *Comité Européen de Normalisation*: A public Standards organization whose mission is to foster the economy of the European Union (EU) in global trading, the welfare of European citizens and the environment.

CENELEC, *Comité Européen de Normalisation Électrotechnique*: A commission responsible for Standardization in the electrotechnical engineering field. CENELEC prepares voluntary Standards, which help facilitate trade between countries, create new markets, cut compliance costs and support the development of a Single European Market.

CIBSE, *Chartered Institution of Building Services Engineers*: The professional body that exists to support the Science, Art, and Practice of building services engineering, by providing its members and the public with first class information and education services and promoting the spirit of fellowship which guides its work. Received its Royal Charter in 1976

CIT, *Chalmers Industriteknik*: A foundation founded by the Chalmers University of Technology that provides access to the universities' expertise and competence, and implements Swedish research.

Comparative tests: Tests that include a series of diagnostic test cases applied to several state-of-the-art energy simulation programs.

DMU, *De Montfort University.*

DP, *Double pane window without shading.*

Empirical validation tests: Tests that include comparing program results with a perfectly performed truth model.

EN, *European Standards*: Documents that have been ratified by one of the 3 European Standards Organizations, CEN, CENELEC or ETSI. They are designed and created by all interested parties through a transparent, open and consensual process.

ETSI, *European Telecommunications Standards Institute*: An Institute that produces globally-applicable Standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and Internet technologies.

Ext. IR Emit., *Exterior Infrared Emittance.*

FF, *Free-Float thermostat strategy where no heating or cooling system is allocated.*

HVAC, *Heating, Ventilation and Air-Conditioning*.

IEA, *International Energy Agency*: An autonomous organization which works to ensure reliable, affordable and clean energy for its 29 member countries and beyond.

Int. IR Emit., *Interior Infrared Emittance.*

ISO, *International Organization for Standardization*: An independent, non-governmental international organization with a membership of 161 national Standards bodies. Through its members, it brings together experts to share knowledge and develop voluntary, consensus-based, market relevant International Standards that support innovation and provide solutions to global challenges.

IT, *Italy*.

Lindab®: An international group that develops, manufactures, markets and distributes products and system solutions for simplified construction and improved indoor climate.

N/A, *Not Applicable.*

NREL, *National Renewable Energy Laboratory*: An organization that develops clean energy and energy efficiency technologies and practices, advances related science and engineering, and provides knowledge and innovations to integrate energy systems at all scales.

Operative temperature: The uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment [1].

SDP, *Double pane window with shading.*

US, *Unites States.*

VUB, *Vrije Universiteit in Brussels*.

Symbols, Definitions, and Units

For the purpose of this thesis, the following symbols and units apply:

Symbol	Definition	Unit
$\overline{T_E}$	The average temperature over the dimensioning day	°C
$\widehat{T_E}$	Temperature amplitude over the dimensioning day	°C
$\overline{T_R}$	Mean radiant temperature	°C
T_1	Room temperature in winter	°C
B	Mean anomaly	Dimensionless
c	Specific heat	$J \cdot kg^{-1} \cdot K^{-1}$
d_m	Thickness of the material in the glazing unit	m
E	Equation of time	minutes
h_r	Radiation conductance in the glazing unit	$W \cdot m^{-2} \cdot K^{-1}$
I_{DH}	Direct radiation on horizontal surface	$W \cdot m^{-2}$
I_{DN}	Direct normal radiation at ground level	$W \cdot m^{-2}$
$I_{D\psi\theta}$	Direct radiation on surface with inclination ψ and θ	$W \cdot m^{-2}$
$I_{R\psi}$	Reflected radiation on surface with inclination	$W \cdot m^{-2}$
I_{SH}	Diffused radiation on horizontal surface	$W \cdot m^{-2}$
I_{SK}	Solar constant beyond atmosphere	$W \cdot m^{-2}$
$I_{S\psi}$	Diffused radiation on surface with inclination ψ	$W \cdot m^{-2}$
I_{TH}	Total radiation on horizontal surface	$W \cdot m^{-2}$
$I_{T\psi\theta}$	Total radiation on tilted surface with ψ and θ	$W \cdot m^{-2}$
K	Sum of components in a questionnaire	Dimensionless
L_{lok}	Longitude	°
m	Air mass coefficient	Dimensionless
n	Day number	Dimensionless
n	Exponent	Dimensionless
P	Atmospheric transmissivity	Dimensionless
R_a	Inner accumulative heat resistance of the structure	$W \cdot m^{-2} \cdot K^{-1}$
R_e	From accumulative layer to outside heat resistance of the structure	$W \cdot m^{-2} \cdot K^{-1}$
R_i	Internal contact resistance	$W \cdot m^{-2} \cdot K^{-1}$
t	Hour of interest	h
t^*	Hour angle	°
T_a	Conditioned zone air temperature	°C
T_E	Dimensioning outdoor temperature	°C
t_{lok}	Local time	h
t_{max}	The hour of the day where the maximum temperature occurs	h
T_{OP}	Operative temperature	°C
t_{sol}	Solar time	h
T_{TS}	Time relative to GMT	h
U	Thermal transmittance	$W \cdot m^{-2} \cdot K^{-1}$
X_{sur}	Surface dimensionless resistance factor	Dimensionless
X_W	Window surface dimensionless resistance factor	Dimensionless

A	Cronbach's alpha	Dimensionless
α'	Azimuth angle	°
α_K	Convective transition factor per person	$W \cdot m^{-2} \cdot K^{-1}$
α_K	Radiation factor per person	$W \cdot m^{-2} \cdot K^{-1}$
B	Solar altitude	°
γ	Vertical azimuth for a surface with orientation θ	°
δ	Declination angle	°
θ	Surface orientation from north	°
ρ	Density	$kg \cdot m^{-3}$
ρ_n	Pane reflectance	Dimensionless
ρ_n	Shading reflectance	Dimensionless
τ_e	Pane direct transmissivity	Dimensionless
τ_e	Shading direct transmissivity	Dimensionless
Φ	Latitude	°

1 Introduction

Since their first use among consultants in the early 1960s [2], a large number of building simulation programs have been developed to model the performance of buildings and to simulate what occupants experience under different conditions. In 1985, a survey was conducted among the International Energy Agency (IEA) countries and it was found that 230 tools were available at that time [3]. Nowadays, the continuing proliferation of building simulation tools means that a wide variety of well-established tools are available in the market. These tools have their own capabilities, and limitations to model a building from a single zone up to a number of zones (e.g. TEKNOsim and IDA-ICE, respectively). However, significant discrepancies can be noted between the results even if the same building is simulated using different programs [4]. Due to differences in algorithms that each software relies on, it is essential to have a diagnostic method that can diagnose the calculations behind a program's interface and identify the sources of errors for the correction procedure [5]. One such diagnostic method has been developed by IEA and National Renewable Energy Laboratory (NREL). The method, developed in 1995, is referred to as Building Energy Simulation Test (BESTEST). The objective of this task was to provide a methodology that comprises of empirical validation, analytical verification and comparative analysis with a number of state-of-the-art programs that participated in the project [6]. Later on, multiple Standards were developed with different tests that could be used to validate the results of a specific tool. The European Standard (EN), British Standard (BS), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and Chartered Institution of Building Services Engineers (CIBSE) are few examples of the organizations that have created different accreditation processes for comparing and testing energy simulation programs.

The revolution and the rapid increase in the level of complexity of buildings architectural design entail advanced computer simulation tools that handle dynamic and complex simulations of buildings. Most of these advanced tools require that the user has some background knowledge in building physics to model the building. In addition to the background knowledge requirement, most of these tools also have a long learning curve before the user is capable of comprehending the interface and understand the meaning of each input. Simplified tools, which are capable of dynamic modelling, are more convenient in the early design stage to make fast and reasonably accurate simulations of the thermal loads and indoor thermal climate. Furthermore, a user who is not an expert in the field of building services can also use these simplified tools without encountering the burden of abundant inputs required by the more advanced tools. Even with their simplicity, these tools can be used to perform dynamic simulations that take into account time-dependent environmental and energy flow parameters including external temperatures, incident solar radiation, thermal mass, and internal gains [7].

1.1 Background

TEKNOsim is a simple tool that is used for indoor thermal climate simulations, calculation of thermal loads and temperature variations during the dimensioning day. The software has been developed by Lindab® – an international group and manufacturer of building, ventilation and indoor climate-related products and system solutions [8]. The program can be used to calculate heating and cooling loads, and to simulate the indoor thermal climate of a building in terms of air temperature, operative temperature, and Predicted Percentage of Dissatisfied (PPD) index. The program can also be used for sizing and selection of a wide range of Lindab products [9, 10]. A new version of the software, *TEKNOsim - version 5*, has been released with major changes in the interface and several new features. The previous version of TEKNOsim was verified by Chalmers Industriteknik (CIT) [9]. It was also compared against the German Guideline VDI 2078 "VDI Cooling Load Regulation" [10]. The new version 5 has been tested and compared against two state-of-the-art building energy simulation tools, *DesignBuilder* and *IDA-ICE* [11]. One of the changes in TEKNOsim5 is related to the graphical user interface, where the user can now model the building in a 3D window with the possibility to exchange models with Computer Aided Drafting (CAD) programs. The new interface also makes the process of defining the input data of the model more flexible and easy to follow. Due to these and other changes made in TEKNOsim5, it was indispensable to validate the new version to make sure that the results of the new implementation are accurate and error-free.

1.2 Aim

"A complex software should not be used when a simple one can adequately address a specific building or energy conservation measure. Complex software does not necessarily yield more accurate results" [14]. The main objective of this thesis is to evaluate the simple and user-friendly simulation tool TEKNOsim 5 through qualitative and quantitative analysis based on conducting a survey and simulating test cases, respectively. The qualitative assessment focuses on the new interface and investigates how users rate various features of the software and navigation experience through different program windows. The quantitative analysis of TEKNOsim 5 is carried out in two main categories:

1. *Analytical verification tests*: This test category uses analytical solutions for specific heat transfer processes under prescribed model conditions [15]. In this thesis, analytical verification tests from the following two Standards have been implemented:
   A. BS EN ISO 13791:2012 "Thermal performance of buildings — Calculation of internal temperatures of a room in summer without mechanical cooling — General criteria and validation procedures" [16].
   B. BS EN 15255:2007 "Energy performance of buildings — Sensible room cooling load calculation — General criteria and validation procedures" [17].
2. *Comparative tests*: This test category includes a series of diagnostic tests cases applied to a number of state-of-the-art energy simulation programs [15].

Comparative tests from ANSI/ASHRAE Standard 140-2011 "Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs" [18] have been applied in this thesis. The tests comprise of a series of diagnostic tests based on the BESTEST [5]. The last Standardized method of testing used in this thesis is CIBSE TM33: 2006 "Tests for software accreditation and verification". This standard provides both analytical and empirical types of tests.

1.3 Scope and limitations

TEKNOsim 5 is a simple tool for single zone simulations, therefore, any test cases that require calculations for more than one zone in a single model have been excluded and considered out of the scope for this study. When validating against ANSI/ASHRAE 140-2011 Standard, 12 out of 18 test cases were covered. These tests are provided in Section 5.2 of the Standard and are related to the building thermal envelope and fabric loads. Simulation cases related to energy demand, minimum annual hourly integrated zone temperature, average annual hourly integrated zone temperature, transmissivity coefficient of windows, shading coefficient of shading devices, annual incident solar radiation, and annual transmitted solar radiation have been regarded outside the scope of the comparative analysis performed in this study. This is due to the limitation of TEKNOsim in performing annual energy simulations.

Compared to more advanced energy simulation software, TEKNOsim 5 requires fewer input data from the user to make a simulation. Most test cases defined by Standards also require detailed input data, which can only be defined in an advanced energy simulation program. For this study, some of the input parameters provided by the Standards have been adjusted, assumed, or disregarded due of the limitation of TEKNOsim in prescribing detailed input data. The following measures have been taken:

- Conversion of hourly ambient temperature profile provided by Standards to the TEKNOsim format.
- Adjustment of inputs that are used by TEKNOsim to calculate the incident solar radiation.
- Modification of the overhang shading device geometry to overcome TEKNOsim modelling limitations.
- Assumption of indoor air climate variables, such as air speed, moisture content, and radiative properties of the occupants, when not prescribed by the Standard.
- Adaptation of thermos-physical properties of different elements when calculating heat capacity due to the difference in approaches used by Standards and TEKNOsim.
- Alteration of internal gains schedule to match the limitation of a maximum of four schedules in TEKNOsim.

These changes in input data will be discussed in more detail in the methodology Section.

2 Methodology

2.1 Qualitative analysis

This Section refers to the assessment of the new interface of TEKNOsim 5 and explains how well the new version performs in terms of graphical representation and normative and informative features. A survey has been conducted on a sample of students in the master's program in Energy-efficient and Environmental Building Design, Faculty of Engineering, Lund University. This sample of students was the first group of users who had the opportunity to work with the TEKNOsim 5 alpha version before the official release of the software to the market. The students, who were working on a design task to implement an HVAC (Heating, Ventilation, and Air-Conditioning) system for a commercial building, used TEKNOsim to find optimal air flows and to select appropriate heating, cooling and ventilation products. After the students had the chance to work with the software and had understood the functionality of its options, they were asked to fill in an online questionnaire. The survey was taken by 18 students. The questions included in the survey can be found in Appendix A. The core and the structure of some of the questions in the survey was borrowed from a previous survey [19] that was intended to evaluate users' needs for building performance simulation tools. The questionnaire consisted of four main sections:

A. General information: This section included four questions on disciplinary background of the respondent, their contact details, their expectations from the software prior to working with it, and the type of HVAC system modelled in TEKNOsim.

B. Feedback on basic features: Questions in this section were intended to evaluate the user perception of the fundamental options of the software including; database, help files, and navigation through different windows.

C. Feedback on in-depth features: In this part, questions related to the specific functions of TEKNOsim were asked. The questions concerned representation of input/output data, default values of the input data, and the range of HVAC systems that could be simulated in TEKNOsim.

D. Future development: This section provided the respondents with a list of features they would like to be added in the future version of the software. The respondents could choose from a provided list of features or could suggest any other measure.

Sections A and D included multiple choice options. However, the respondents were allowed to add alternate options if their response to the question was not included in the provided list of choices. Sections B and C were built using a Likert scale to rate the level of agreement or disagreement with each statement. The responses were then converted to a numerical scale to test the reliability of the questionnaire.

2.1.1 Reliability of the questionnaire

Before conducting any statistical analysis or extracting data from the survey, the answers from the respondents were analysed to investigate the reliability of the survey and its use for scientific research. The measurement of the reliability was deduced by calculating Cronbach's alpha, which measures the internal consistency of a test based on the correlations amongst the respondents' answers to the set of questions [20]. Cronbach's alpha can be calculated using the so called "Formula 20" presented by Kuder and Richardson [21]:

$$\alpha = \frac{k}{k-1}\left(1- \frac{\sum_{j=1}^{k} var(x_j)}{var(x_0)}\right) \tag{1}$$

where α is Cronbach's alpha, k is the number of items, $\sum_{j=1}^{k} var(x_j)$ is the sum of variances of the separate test item, and $var(x_0)$ is the variance for the set of person total test scores.

Cronbach's alpha was only applied on sections B and C of the survey, which used the Likert scale for the questions. The coefficient was calculated separately for each section as the scale differs for section B and section C. Prior to the calculation of Cronbach's alpha, coding of the Likert scale had to be reversed in order to get the proper application of the coefficient [22].

2.2 Quantitative analysis

2.2.1 EN ISO 13791:2012

This Section covers the analytical verification of TEKNOsim 5 against the EN ISO 13791:2012 "Thermal performance of buildings — Calculation of internal temperatures of a room in summer without mechanical cooling — General criteria and validation procedures". This Standard focuses on the calculations of the maximum, average and minimum operative temperatures on the design day (July 15), assuming no mechanical cooling. Test cases included in the proposed Standard [16] are divided into two main categories and are described as: 1) Geometry A, and 2) Geometry B. The isometric layout of the two geometries is shown in Figure 2.1, where all dimensions are in meters and the windows face the west orientation. The window in geometry A is a single pane window glass with external shading device, while the window in geometry B is a double pane window glass with external shading device.

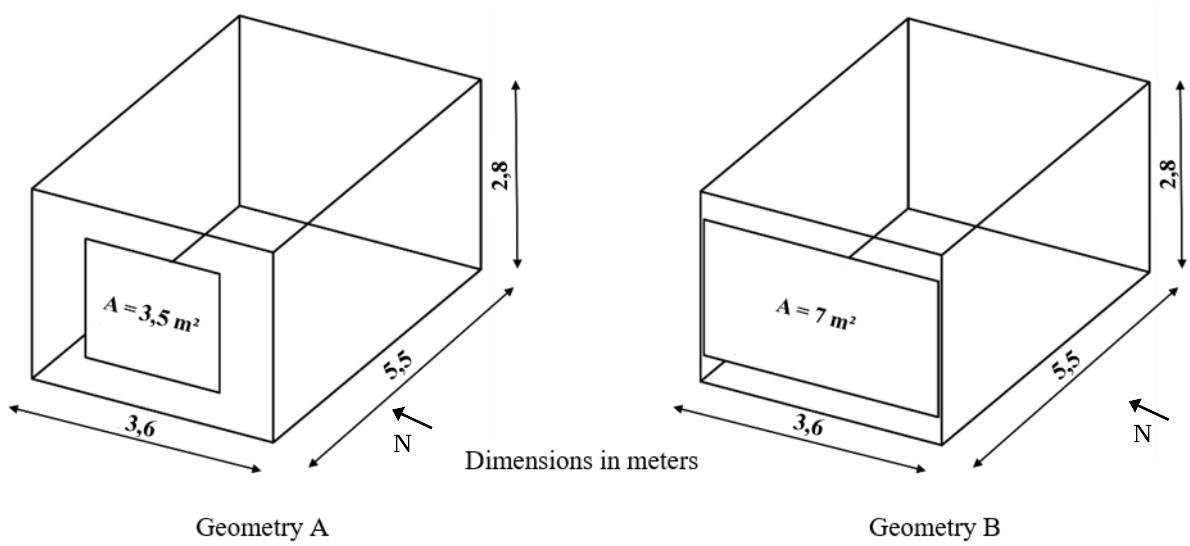

Figure 2.1: Isometric view of the room geometry.

Both geometries have three different room types. In order to test the ability of the program to simulate zones with different thermal envelope characteristics, properties and the adjacency of the room elements are different. Furthermore, for each room type, three different ventilation flow rates are considered. In total there are 18 test cases for this Standard – nine cases corresponding to each geometry, see Table 2.2.

2.2.1.1 Input data

As mentioned before, TEKNOsim is a simple tool developed for performing quick simulations. Hence, some of the inputs used for simulations in this study were different than those prescribed in the Standard. Some other inputs had to be assumed due to TEKNOsim limitations in defining those inputs. Table 2.1 provides a comparison of the inputs specified in the Standard with those used in TEKNOsim simulations.

Table 2.1 - Input data prescribed in EN ISO 13791:2012 and used in TEKNOsim simulations.

	EN ISO 13791:2012		TEKNOsim	
	Geometry A	**Geometry B**	**Geometry A**	**Geometry B**
Climate data:				
Latitude / N	40	52	40	52
Longitude / °	0	0	0	0
Outdoor temperature / °C	Figure 2.2	Figure 2.2	Figure 2.2	Figure 2.2
Solar radiation	Figure 2.3	Figure 2.3	Figure 2.3	Figure 2.3
Time zone relative to GMT	0	0	0	0
Ground reflectance[1]	0,18	0,20	0,18	0,20
Construction thermal transmittance (U-value):				
External wall Type 1 / $W·m^{-2}·K^{-1}$	0,50		0,50	
Internal wall Type 2 / / $W·m^{-2}·K^{-1}$	0,36		0,36	
Ceiling/floor Type 3 / / $W·m^{-2}·K^{-1}$	0,75		0,75	
Ceiling/floor Type 4 / / $W·m^{-2}·K^{-1}$	0,24		0,24	
Roof Type 5 / / $W·m^{-2}·K^{-1}$	0,44		0,44	
Single pane window with shading:				
U-value / $W·m^{-2}·K^{-1}$	3,58		3,58	
Window system g-value[2]	N/A		0,23 Calculated using Parasol [23]	
Pane direct transmissivity, τ_e	0,84		N/A	
Pane reflectance, ρ_n	0,08		N/A	
Shading direct transmissivity, τ_e	0,20		N/A	
Shading reflectance, ρ_n	0,50		N/A	
Double pane window with shading:				
U-value / $W·m^{-2}·K^{-1}$	3,21		3,31	
Window system g-value	0,20		0,20	
Pane direct transmissivity, τ_e	0,84		N/A	
Pane reflectance, ρ_n	0,08		N/A	
Shading direct transmissivity, τ_e	0,20		N/A	
Shading reflectance, ρ_n	0,50		N/A	
Convective heat transfer coefficient:				
Vertical wall / $W·m^{-2}·K^{-1}$	2,50		2,50	
Heat flow upwards / $W·m^{-2}·K^{-1}$	5,00		5,00	
Heat flow downwards / $W·m^{-2}·K^{-1}$	0,70		1,00*	
External heat convective / $W·m^{-2}·K^{-1}$	8,00		8,00	
Convective portion of internal gains	50 %		50 %	

*Minimum value possible in TEKNOsim.

The Standard provides the outdoor temperature for the two geometries as hourly values for the design day. However, in TEKNOsim the outdoor temperature is defined in terms of minimum, maximum, and average temperature values, in addition to prescribing the hour during the design day at which the maximum temperature occurs. From these inputs, the temperature profile for the design day is obtained. It follows a sine-wave curve and is calculated by applying the following equation [24].

$$T_E(t) = \overline{T_E} + \widehat{T_E} \cos\left(\pi \frac{t - t_{max}}{12}\right) \tag{2}$$

In the above equation $T_E(t)$ is the outdoor temperature at any given hour, $\overline{T_E}$ is the average temperature of the dimensioning day, $\widehat{T_E}$ is the temperature amplitude of the dimensioning day, t is the hour at which the outdoor temperature is calculated and t_{max} is the hour of the day at which the maximum temperature occurs. Figure 2.2 shows the temperature oscillation during the design day as prescribed in the EN 13791 and calculated by TEKNOsim based on Equation 2. The Standard specifies that the maximum temperature occurs at 15:00 hours, however, if this hour was assigned to TEKNOsim, the deviation between the two curves (solid and dashed lines) is notable. This deviation would affect the heat accumulation in the building envelope during the day. Thus, the hour where the maximum temperature occurs was shifted to 16:00 hours for TEKNOsim

[1] The value of the ground reflectance was deduced from the ratio between reflected radiation to the direct and diffused radiation.

[2]The g-value of the double pane window system was taken from the BS EN ISO 15255:2007 which has the same window system details.

simulations. The dotted line in Figure 2.2 represents the influence of this change. As can be seen from the figure, the deviation between TEKNOsim and EN 13791 is decreased with the time shift. Hence, the values of the dotted lines in Figure 2.2 were used in the simulations of test cases.

In EN 13791, the solar radiation during the day is defined in terms of direct, diffused and reflected radiation on horizontal and vertical west surfaces. TEKNOsim only accepts two inputs, i.e. solar constant beyond atmosphere (I_{SK}) and atmospheric transmissivity (P), regarding the solar radiation. These inputs are then converted to hourly incident radiation. An analysis based on the algorithm used in TEKNOsim was carried out to understand the differences between the EN 13791 and TEKNOsim in terms of the hourly solar radiation. The comparison was made for the hourly total radiation on a horizontal surface and the hourly total radiation on the vertical west surface.

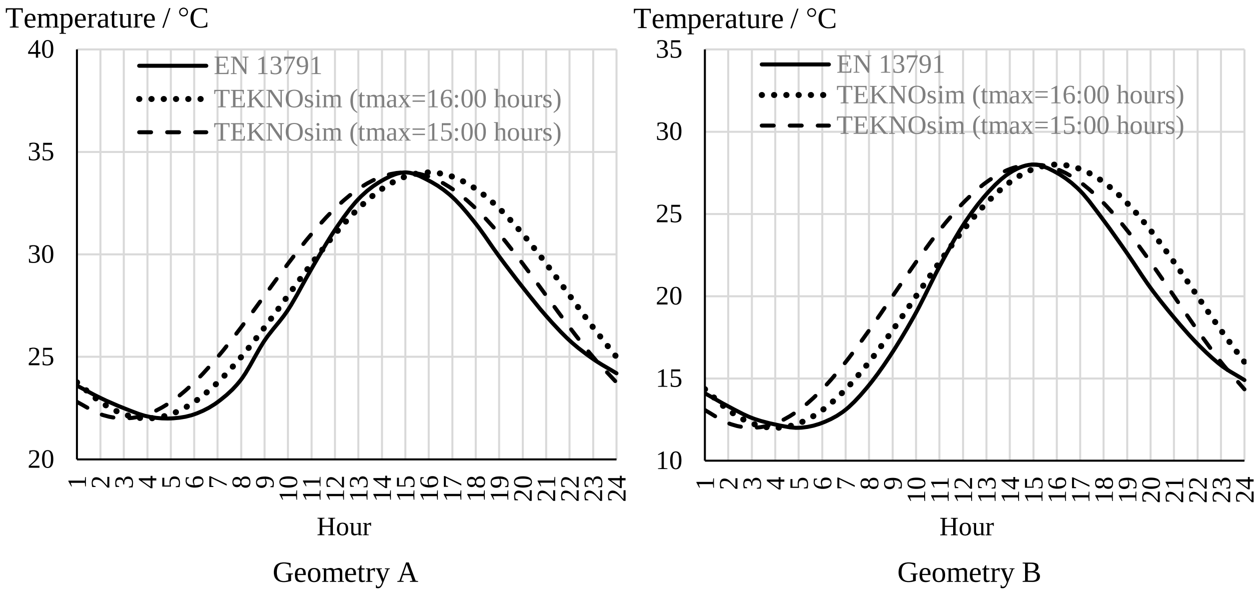

Figure 2.2: Outdoor temperatures of EN 13791 against TEKNOsim for the 15th of July.

The following series of equations describes the mathematical procedures, in sequence, that TEKNOsim uses for calculating the hourly solar radiation [24]. The declination angle, δ, of the earth's equator depends on the day number, n, and is deduced by the following formula:

$$\delta = 23{,}45 \sin\left(360 \ \frac{284 + \mathrm{n}}{365}\right) \qquad (3)$$

The mean anomaly, B, of the earth's elliptical orbit is calculated as follows:

$$B = (\mathrm{n} - 1)\,\frac{360}{365} \qquad (4)$$

The equation of time, E, is deduced by the following formula:

$$E = 229{,}2\ (0{,}000075 + 0{,}001868\cos B - 0{,}032077\sin B - 0{,}014615\cos 2B - 0{,}04089\sin 2B) \qquad (5)$$

The solar time that is based on the sun's position in the sky is given as:

$$t_{sol} = t_{lok} + \frac{\mathrm{L_{lok}}}{15} - \mathrm{T_{TS}} + \frac{E}{15} \qquad (6)$$

where t_{sol} is the solar time, t_{lok} is the local time, $\mathrm{L_{lok}}$ is the site longitude and $\mathrm{T_{TS}}$ is the time relative to GMT. The hour angle, t^*, is calculated by applying the following formula:

$$t^* = (t_{sol} - 12)15 \qquad (7)$$

The solar altitude, β, which indicates the height of the sun in the sky is calculated using the site latitude Φ as:

$$\beta = \arcsin(\sin\Phi \sin\delta + \cos\Phi \cos\delta \cos t^{*}) \tag{8}$$

The solar azimuth angle, α´, along the horizon is determined as:

$$\alpha' = \arccos\left(\frac{\sin\beta \sin\Phi - \sin\delta}{\cos\beta \cos\Phi}\right) \tag{9}$$

Air mass, m, which is used in the calculation of direct normal radiation, is calculated as:

$$m = \frac{1}{\sin\beta} \tag{10}$$

The vertical azimuth, γ, of the surface is determined from the surface orientation from the north, θ, as:

$$\gamma = 180 - \theta - \alpha', \text{ if } t_{sol} < 12 \quad , \quad \gamma = 180 + \theta - \alpha', \text{ if } t_{sol} \geq 12 \tag{11}$$

The direct normal radiation at ground level, I_{DN}, is calculated as:

$$I_{DN} = I_{SK} P^{m} \tag{12}$$

The direct normal radiation on the horizontal surface, I_{DH}, is obtained from:

$$I_{DH} = I_{DN} \sin\beta \tag{13}$$

The diffused radiation on horizontal surface, I_{SH}, is calculated as:

$$I_{SH} = 0{,}5\, I_{SK} \sin\beta \frac{1 - P^{m}}{1 - 1{,}4 \ln P} \tag{14}$$

The total radiation on horizontal level, I_{TH}, is derived as:

$$I_{TH} = I_{SH} + I_{DH} \tag{15}$$

The diffused radiation on tilted surface, $I_{S\psi}$, is determined from the angle of the tilted surface from a horizontal level, ψ, as. :

$$I_{S\psi} = I_{SH} \cos^{2}(\psi/2) \tag{16}$$

The reflected radiation on tilted surface, $I_{R\psi}$, is deduced from:

$$I_{R\psi} = (1 - \cos^{2}(\psi/2))\, \rho\, I_{TH} \tag{17}$$

The direct radiation on tilted surface, $I_{D\psi\theta}$, is calculated as:

$$I_{D\psi\theta} = I_{DN} (\sin\beta \cos\psi + \cos\beta \cos\gamma \sin\psi) \tag{18}$$

Finally, the total radiation on tilted surface, $I_{T\psi\theta}$, is obtained from:

$$I_{T\psi\theta} = I_{R\psi} + I_{S\psi} + I_{D\psi\theta} \tag{19}$$

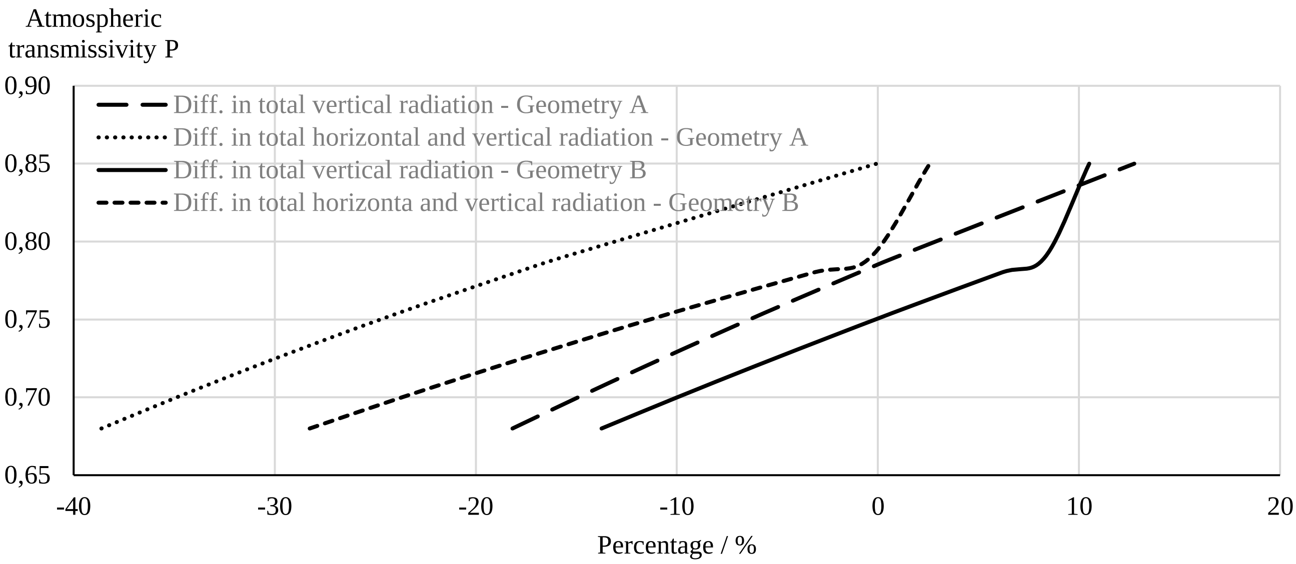

Figure 2.3: Impact of the atmospheric transmissivity on the total radiations.

The results of Equations 3 to 19 were obtained by using the input data from Table 2.1 and the default values used by TEKNOsim. A comparison was performed between the EN 13791 and TEKNOsim for the total radiation on a horizontal surface and the total radiation on the vertical west surface. To decrease the differences in comparison results, a sensitivity analysis was performed to optimize the atmospheric transmissivity value, *P*. The conformity ratio between the solar radiation values in the EN 13791 and TEKNOsim is shown in Figure 2.3. Test cases 1 and 2 in Table 2.2 consider only the total radiation on the vertical west surface, as all other surfaces are adiabatic. Therefore, as Figure 2.3 shows, the minimum difference in the total vertical radiation occurs when *P* equals 0,85 and 0,79 for geometry A and B, respectively. On the other hand, Test case 3 considers both vertical and horizontal radiations due to the roof construction that is exposed to the external environment. In this case, and as Figure 2.3 demonstrates, *P* was set to 0,79 and 0,75 for geometry A and B, respectively. All test cases were defined with their corresponding *P* values, whereas the value of I_{SK} was kept 1367 $W \cdot m^{-2}$.

The final comparison of the incident solar radiation between the EN 13791 and TEKNOsim is shown in Figure 2.4. The upper left graph illustrates the total radiation on the vertical west surface for the climate data of geometry A with *P* = 0,85 as obtained from Figure 2.3 for test cases 1 and 2. The incident radiation from 05:00 to 12:00 hours in the EN 13791 is given as the diffused and reflected radiation. The effect of the direct radiation on the west façade is negligible due to the position of the sun in the sky during these hours. In the algorithm that TEKNOsim uses for the calculation of incident solar radiation, there is an underestimation of the values of diffused and reflected radiation during morning hours. On the other hand, for geometry A, the peak radiation calculated in TEKNOsim exceeds those provided in the EN 13791 by almost 20 %. The opposite happens for geometry B with around 7 % decrease in peak radiation. The two lower graphs illustrate the total radiation on a horizontal surface as well as the total radiation on a vertical surface for geometry A and B together with their corresponding *P* value when these two incident radiations were considered for test case 3. Even though the purpose of the sensitivity analysis was to obtain the optimal value of the atmospheric transmissivity to minimize the differences between EN 13791 and TEKNOsim, the deviation could still be observed for any given time period. Nevertheless, the summation of solar radiation was more or less the same. This hourly deviation would influence the heat storage in the structure which, consequently, would affect the final output.

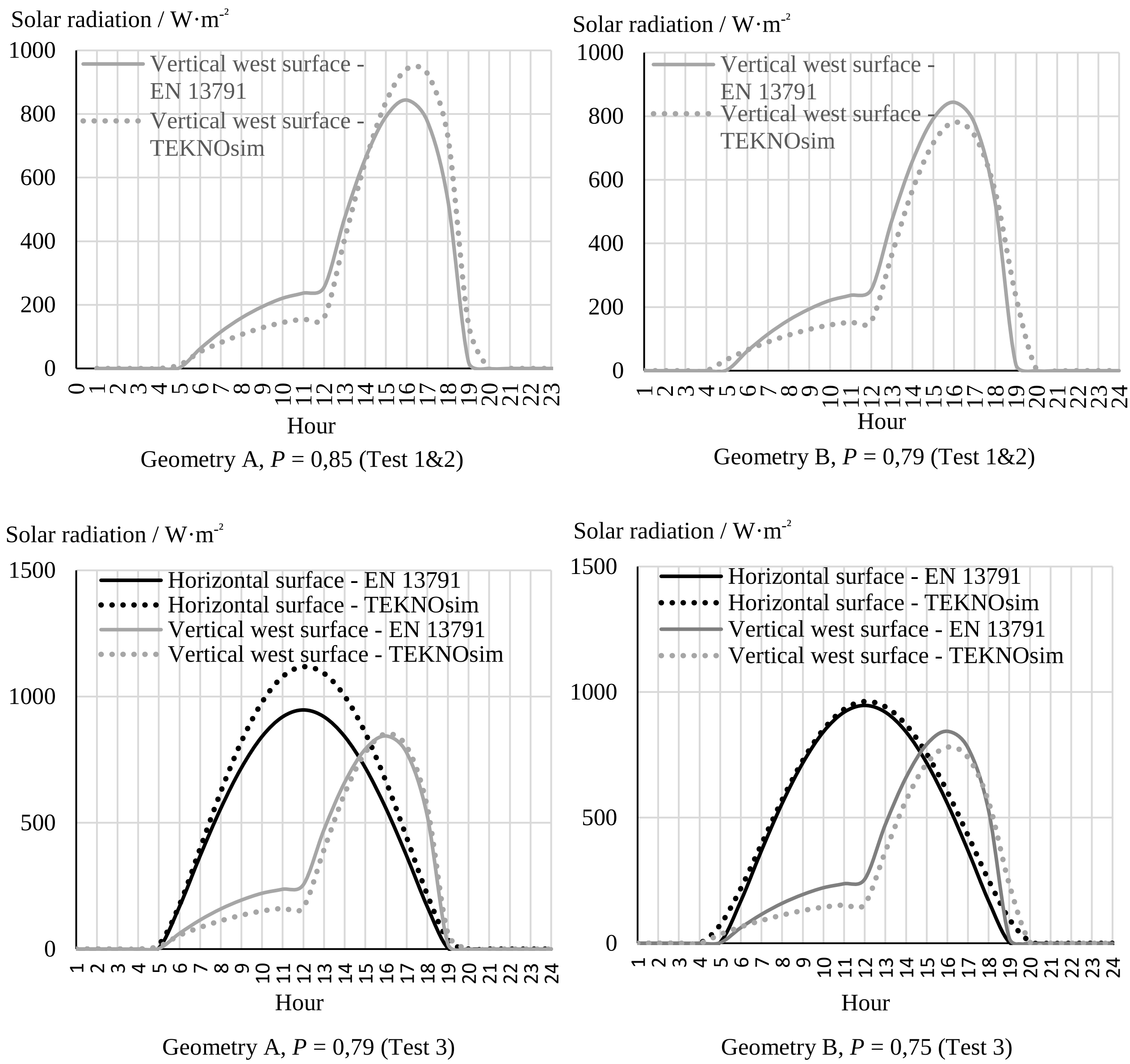

Figure 2.4: Solar radiation comparison between EN 13791 and TEKNOsim for the different test cases.

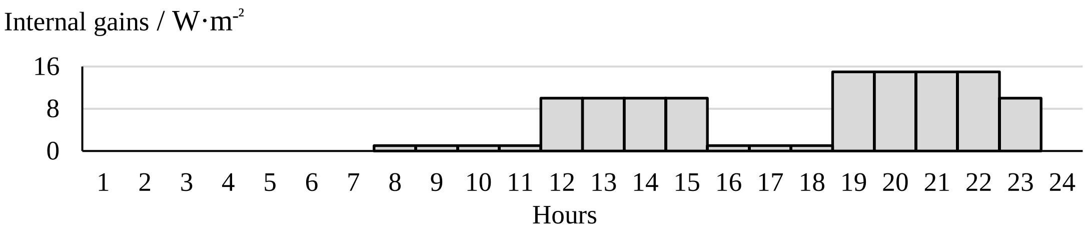

Figure 2.5: Internal gains for all test cases.

The schedule of the internal gains in heat produced per floor area is shown in Figure 2.5. TEKNOsim can model up to two different schedules for each internal gain category (i.e. lighting and devices). However, as the internal gains of the EN 13791 are given in five schedules, a modified scheduled was defined in TEKNOsim. The only difference in the modified schedule is that between 22:00 and 23:00 hours, TEKNOsim considers heat gains of 15 $W·m^{-2}$ instead of 10 $W·m^{-2}$. The ventilation flow is given in the EN 13791 in three different patterns; a, b and c.

Pattern a: Constant air flow during the day (1 ACH).

Pattern b: Constant air flow from 06:00 to 18:00 hours (0,5 ACH), otherwise (10 ACH).

Pattern c: Constant air flow during the day (10 ACH).

2.2.1.2 Test cases

The 18 tests cases that represent the differences between models in terms of glazing, construction and ventilation patterns are shown in Table 2.2. The data in this table is complementary to the information provided in Table 2.1.

Table 2.2 - Test cases included in EN 13791.

Geometry	Test No.	Ventilation pattern	Glazing		West external wall	Adiabatic internal wall	Adiabatic ceiling	Adiabatic floor	Roof
			Area / m²	Type					
A	1	a/b/c	3,5	Single	Type 1	Type 2	Type 4	Type 4	-
	2	a/b/c			Type 1	Type 2	Type 3	Type 3	-
	3	a/b/c			Type 1	Type 2	-	Type 3	Type 5
B	1	a/b/c	7,0	Double	Type 1	Type 2	Type 4	Type 4	-
	2	a/b/c			Type 1	Type 2	Type 3	Type 3	-
	3	a/b/c			Type 1	Type 2	-	Type 3	Type 5

In this thesis, the designated format to refer to these cases is; geometry.test.number of ventilation pattern. For example, case B.2.b refers to the model of geometry B with test number 2 and ventilation pattern b.

2.2.1.3 Output requirements

The Standard requires that following should be calculated for all 18 test cases [16]:

1. Daily maximum value of the operative temperature.
2. Daily average value of the operative temperature.
3. Daily minimum value of the operative temperature.

The output of these values from the tested program, in this case TEKNOsim 5, shall give a deviation of less than ± 0,5 K. The EN 13791 defines the operative temperature as the arithmetic mean between air temperature and mean radiant temperature. Therefore, in order to have the same model conditions for the comparison process, it was crucial to comprehend how TEKNOsim determines the operative temperature. Equation 20 shows the algorithm used in the software for the calculation of the operative temperature.

$$T_{OP} = \frac{\alpha_K \, T_I + \alpha_R \, \overline{T_R}}{\alpha_K + \alpha_R} \qquad (20)$$

Where T_{OP} is the calculated operative temperature, T_I is the room air temperature, $\overline{T_R}$ is the mean radiant temperature, α_K is the convective transition factor per person and α_R is the radiation factor per person. The factors α_K and α_R depend on the indoor air speed and the radiative heat portion of one person in the zone. When modelling the test cases, the indoor air speed was set to zero, which in turn set α_K to zero. Hence, the operative temperature calculated from Equation 20 became equal to the mean radiant temperature. Eventually, a correction of the operative temperature output from TEKNOsim was made by calculating the arithmetic mean of air and operative temperatures to make the comparison against the Standard.

2.2.2 EN 15255:2007

This Section covers the second part of the analytical verification of TEKNOsim. The European Standard EN 15255:2007 “Energy performance of buildings — Sensible room cooling load calculation — General criteria and validation procedures” is a complementary standard that gives the general criteria and validation process for the building part of energy simulation models [17]. The difference between this Standard and EN 13791:2012 is the inclusion of cooling load calculations in test cases. The isometric layout of the room is presented in Figure 2.6 where the exact model of geometry B from EN13791 is used. The external wall with the opening is facing the west orientation. In this Standard also, the simulation of test cases is performed for the dimensioning day of 15th of July.

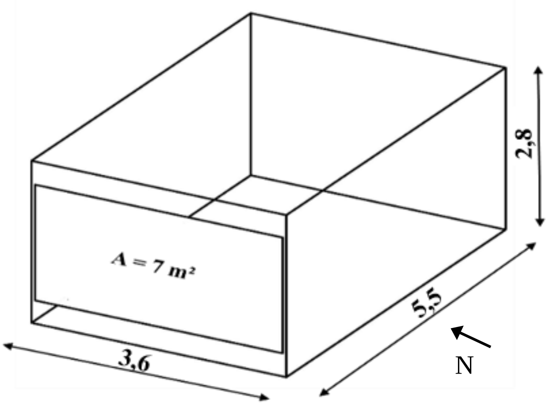

Figure 2.6: Isometric view of the test room in EN 15255.

2.2.2.1 Input data

The input data of the test cases are similar to the inputs of geometry B from Section 2.2.1.1 but with minor changes in climate data and the glazing system. The input data is shown in Table 2.3.

Table 2.3 - Input data for test cases of EN 15255:2007 and TEKNOsim.

	EN 15255:2007	**TEKNOsim**
Climate data:		
Latitude / N	52	52
Longitude / °	0	0
Outdoor temperature / °C	Figure 2.7	Figure 2.7
Solar radiation	Figure 2.8	Figure 2.8
Time zone relative to GMT	0	0
Ground reflectance[1]	0,20	0,20
Construction thermal transmittance (U-value):		
External wall Type 1 / $W \cdot m^{-2} \cdot K^{-1}$	0,50	0,50
Internal wall Type 2 / $W \cdot m^{-2} \cdot K^{-1}$	0,36	0,36
Ceiling/floor Type 3 / $W \cdot m^{-2} \cdot K^{-1}$	0,75	0,75
Ceiling/floor Type 4 / $W \cdot m^{-2} \cdot K^{-1}$	0,24	0,24
Double pane window with shading (SDP):		
U-value / $W \cdot m^{-2} \cdot K^{-1}$	2,21	2,21
Window system g-value	0,20	0,20
Pane direct transmissivity τ_e	0,84	N/A
Pane reflectance ρ_n	0,08	N/A
Shading direct transmissivity τ_e	0,20	N/A
Shading reflectance ρ_n	0,50	N/A
Double pane window without shading (DP):		
U-value / $W \cdot m^{-2} \cdot K^{-1}$	2,69	2,69
Window system g-value	0,77	0,77
Pane direct transmissivity τ_e	0,84	N/A
Pane reflectance ρ_n	0,08	N/A
Shading direct transmissivity τ_e	0,20	N/A
Shading reflectance ρ_n	0,50	N/A
Convective heat transfer coefficient:		
Vertical wall / $W \cdot m^{-2} \cdot K^{-1}$	2,50	2,5
Heat flow upwards / $W \cdot m^{-2} \cdot K^{-1}$	5,00	5
Heat flow downwards / $W \cdot m^{-2} \cdot K^{-1}$	0,7	1,00*
External heat convective / $W \cdot m^{-2} \cdot K^{-1}$	8,00	8,00

*Minimum value possible in TEKNOsim.

[1] The value of the ground reflectance was based on the ratio between reflected radiation to the direct and diffused radiation.

The outdoor temperature profile in TEKNOsim was deduced using Equation 2. It was also found that the one-hour delay from 15:00 to 16:00 hours in the occurrence of the maximum temperature would decrease the deviation between Standard and TEKNOsim results, see Figure 2.7. Calculations of the incident solar radiation were performed by implementing Equations 3 to 19 to find the optimal value of P. The P and I_{SK} values in TEKNOsim were 0,79 and 1367 W·m^{-2}, respectively. Test cases included in EN 15255 only consider the vertical incident radiation on the west surface as all other surfaces are adiabatic. The distribution of the total radiation on the vertical west façade is shown in Figure 2.8.

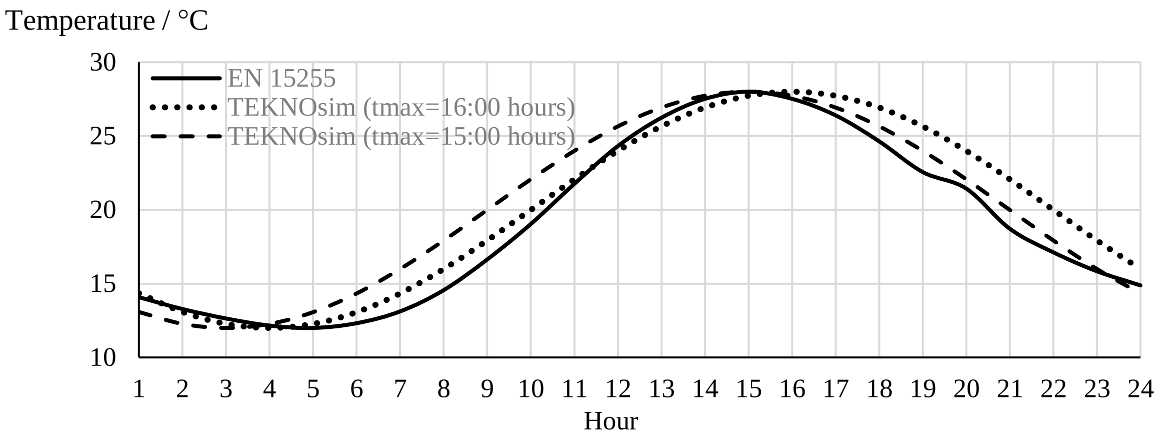

Figure 2.7: Comparison of outdoor temperatures from EN 15255 and TEKNOsim for 15th of July.

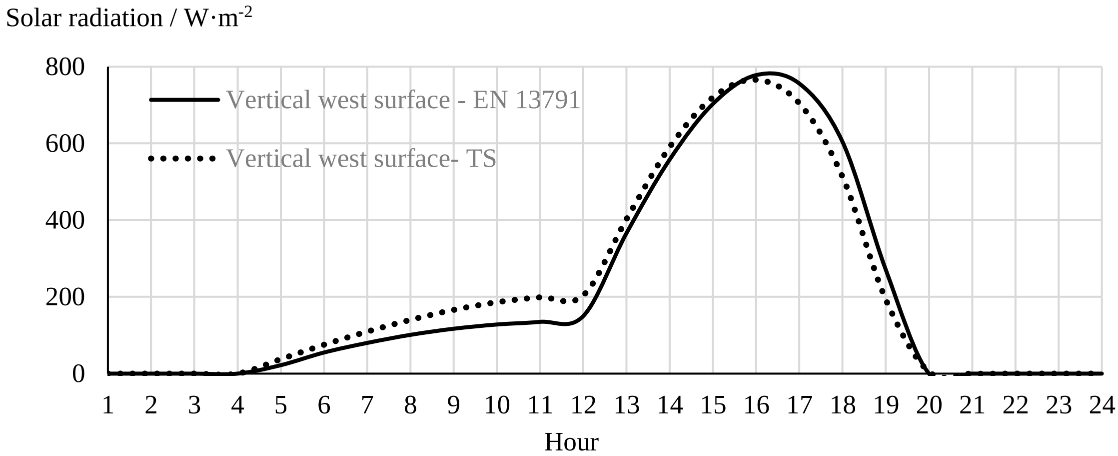

Figure 2.8: Comparison of solar between EN 15255 and TEKNOsim for all test cases.

It can be seen that for both outdoor temperatures and solar radiations, the difference between the values prescribed by the Standard and calculated by TEKNOsim is marginal. The two curves representing EN 15255 inputs and TEKNOsim calculations are more or less overlaying on each other.

2.2.2.2 Test cases

There are 15 cases that have to be modelled in the EN 15255. Six of them have been excluded from this work due to the reasons explained below.

- Test 5: This test requires the thermostat control temperature of the cooling system to be controlled by the operative temperature. When this type of simulation was performed in TEKNOsim, a bug and error message occurred and the simulation crashed. This bug only occurred in the TEKNOsim version used for this study.
- Test 11: For this test, the mechanical system had a given maximum cooling power. TEKNOsim is also a selection tool for Lindab® products and can, hence, simulate a number of cooling products. For this test, different cooling products with same cooling capacity gave different simulation results. Since each cooling product has its own radiative properties and thermal performance, and because there is no option in TEKNOsim to impose a certain equipment capacity, this test was excluded from this study.

- Test 12: Same reason as for Test 5.
- Test 13: The sun shading device for this test was working for a given time period during the day. It is not possible to define a scheduled shading device in TEKNOsim 5.
- Test 14: For this test, the chilled floor at a fixed temperature is the prescribed cooling system. The heat is removed by convection and radiation with no thermal mass or external losses. This type of model conditions could not be defined in TEKNOsim.
- Test 15: Same as Test 14 except that the cooling surface is chilled ceiling.

The other nine test cases are presented in Table 2.4 together with their distinctive characteristics.

Table 2.4 - Test cases included in EN 15255.

Test No.	Ventilation/ ACH	Glazing	Internal gains / W·m^{-2}	Cooling system	West external wall	Adiabatic internal wall	Adiabatic ceiling	Adiabatic floor
1	0	SDP	20-convective and 30-radiative from 08:00 to 18:00	Air system with air temperature control (26 °C) continuous operation	Type 1	Type 2	Type 4	Type 4
2	0	SDP	20-convective and 30-radiative from 08:00 to 18:00	Air system with air temperature control (26 °C) continuous operation	Type 1	Type 2	Type 3	Type 3
3	0	SDP	20-convective from 08:00 to 18:00	Air system with air temperature control (26 °C) continuous operation	Type 1	Type 2	Type 4	Type 4
4	0	DP	20-convective and 30-radiative from 08:00 to 18:00	Air system with air temperature control (26 °C) continuous operation	Type 1	Type 2	Type 4	Type 4
6	0	SDP	20-convective and 30-radiative from 08:00 to 18:00	Air system with air temperature control (26 °C) from 08:00 to 18:00	Type 1	Type 2	Type 4	Type 4
7	0	SDP	20-convective and 30-radiative from 08:00 to 18:00	Air system with air temperature control (26 °C) from 08:00 to 18:00	Type 1	Type 2	Type 3	Type 3
8	0	SDP	20-convective from 08:00 to 18:00	Air system with air temperature control (26 °C) from 08:00 to 18:00	Type 1	Type 2	Type 4	Type 4
9	0	DP	20-convective and 30-radiative from 08:00 to 18:00	Air system with air temperature control (26 °C) from 08:00 to 18:00	Type 1	Type 2	Type 4	Type 4
10	2 with external air temperature from 21:00 to 08:00 otherwise 0	SDP	20-convective and 30-radiative from 08:00 to 18:00	Air system with air temperature control (26 °C) from 08:00 to 18:00	Type 1	Type 2	Type 4	Type 4

2.2.2.3 Output requirements

For each of the test cases, three outputs should be calculated from the software. The calculated outputs should comply with their corresponding conditions defined in the Standard [17]. The conditions include:

1. Daily maximum value of the operative temperature for a simulation time step of one hour. The maximum hourly operative temperature from TEKNOsim should be within ± 0,5 K of the EN 15255 reference value.

2. Maximum cooling power in Watts for a simulation time step of one hour. The relative difference between TEKNOsim output and EN 15255 reference value should not exceed ± 5 % for this output.
3. Average cooling power in Watts for a simulation time step of one hour during the dimensioning day. The relative difference of daily average cooling power between TEKNOsim and the reference value also should not exceed ± 5 %.

The output of the operative temperature was also corrected using the approach discussed in Section 2.2.1.3.

2.2.3 ANSI/ASHRAE 140-2011

ANSI/ASHRAE 140 provides extensive series of diagnostic tests that are based on the BESTEST project. The comparative tests were implemented in several building energy simulation computer programs in cooperation with a number of organizations. These computer programs and organizations are listed in Table 2.5 [6].

Table 2.5 - Computer programs used in the BESTEST task.

Computer program	Organization
BLAST 3.0 Level 193 V.1	• NREL, United States (US). • Politecnico di Torino, Italy (IT).
DOE2.1D Level 14	NREL, US.
ESP-RV8-H	De Montfort University (DMU), Leicester, United Kingdom.
SERIRES/SUNCOD	NREL, US.
S3PAS	Universidad de Sevilla, Spain.
TASE	Tempere University, Finland.
TRNSYS 13.1	• Vrije Universiteit (VUB), Brussels, Belgium. • Building Research Establishment (BRE), United Kingdom.

The scope of this Standard, described in Section 5.2 of the Standard is related to "Building Thermal Envelope and Fabric Load Tests" [18]. These tests are designed to assess the ability of the program to model and simulate different conditions in a single zone. These conditions include thermal mass, heat transfer mechanism, shading devices and setback thermostat control. The isometric view of the base case (case 600) is shown in Figure 2.9, where the transparent windows face the south orientation. The in-depth test cases were excluded from this study since that they require advanced inputs to describe and define the radiative properties of the surface in the model. These inputs cannot be defined in TEKNOsim. In order to increase the comparison sample, two additional simulation programs, named DesignBuilder [12] and IDA-ICE [13], were included in the comparison. The two programs also do not present results for the in-Depth cases of the Standard.

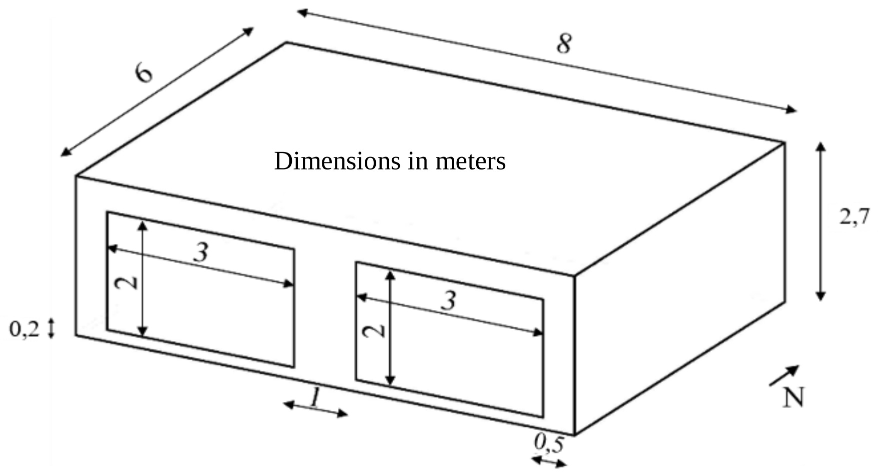

Figure 2.9: Isometric view of the base case (case 600).

2.2.3.1 Test cases and input data

The ANSI/ASHRAE 140-2014 Standard provides comprehensive input data that can be used in advanced simulation tools, where such inputs can be defined. However, as discussed earlier in Section 1.3, TEKNOsim is a simple tool and requires limited input data. Hence, many of the inputs provided by the Standard cannot be defined in TEKNOsim. This Section covers the test case simulations using the input data from the Standard. In accordance with the Standard's recommendations, the input data not provided by the Standard was disregarded when performing the simulations [18]. Test cases included in the building thermal envelope and fabric load tests are divided into two main categories: 1) Basic Tests and 2) In-Depth Tests. The total number of test cases for basic and in-depth categories are 18 and 22, respectively. For this work, 6 test cases were excluded from the basic tests category due to the limitation of TEKNOsim to model those test cases. Tests from in-depth category were not included in this study.

The standard subdivides basic test cases into three categories: Low mass tests, high mass tests, and free-float tests. The free-float tests do not consider any mechanical heating or cooling system. The flowchart in Figure 2.10 shows the 12 basic test cases considered in this work and their correlation. Firstly, test case 600, shown in Figure 2.9, was modelled using the input data from Table 2.6. The three other low mass test cases were similar to test case 600 except for changes in the window shading, window orientation, and night ventilation. Test case 900 was the base model for high mass test cases. This test case is similar to test case 600 except for the change in the thermal mass of the building envelope as shown in Table 2.6. The differences between other three high mass test cases, i.e. case 910, 920 and 950, and the base test case, i.e. case 900, are similar to those between low mass test cases and their base case. The final category of the basic test cases is the free-float tests, associated to test cases 600 and 650, and 900 and 950. Free-float cases are labelled as 600 FF, 650 FF, 900 FF and 950 FF. The only change between these tests and the free-float cases is the exclusion of mechanical heating or cooling system.

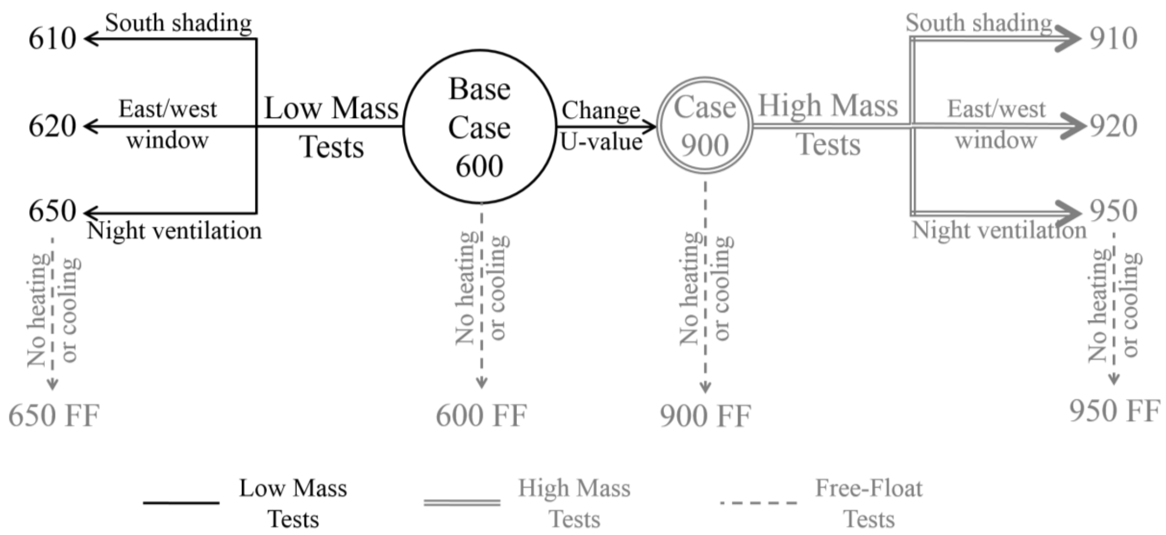

Figure 2.10: Flowchart of the Basic Tests configurations.

Table 2.6 - Comparison of input data prescribed in ANSI/ASHRAE 140-2014 Standard and used for TEKNOsim simulations

	ANSI/ASHRAE 140-2011	TEKNOsim
Climate data:		
Latitude / °	39,80° N	39,80° N
Longitude / °	104,90° W	104,90° W
Outdoor temperature / °C	Annual hourly data	Max, min, and average for the dimensioning months
Solar radiation	Annual hourly data	Solar constant beyond atmosphere = 1377 $W \cdot m^{-2}$
Time zone relative to GMT	-7	-7
Infiltration / ACH	0,41	0,41
Ground reflectance	0,20	0,20
Construction thermal transmittance (U-value) - Low mass cases:		
External wall / $W \cdot m^{-2} \cdot K^{-1}$	0,51	0,51
Floor / $W \cdot m^{-2} \cdot K^{-1}$	0,03	0,07*
Roof / $W \cdot m^{-2} \cdot K^{-1}$	0,31	0,31
Heavy mass cases:**		
External wall	0,51	0,51
Floor	0,03	0,07*
Roof	0,31	0,32
Double pane clear window:		
U-value / $W \cdot m^{-2} \cdot K^{-1}$	3,00	3,00
Window system g-value	0,79	0,79
Thermostat control strategy:		
Heating	On if T_a[1] < 20 °C Otherwise, Heat = off	On if T_a < 20 °C Otherwise, Heat = off
Cooling	On if T_a > 27 °C Otherwise, Cool = off	On if T_a > 27 °C Otherwise, Cool = off
Internal sensible heat gains:	200 W, continuously 60 % radiative 40 % convective	200 W, continuously Radiative gains not prescribed[2] 40 % convective
Convective heat transfer coefficient:		
Vertical wall / $W \cdot m^{-2} \cdot K^{-1}$	8,29	5,00***
Heat flow upwards / $W \cdot m^{-2} \cdot K^{-1}$	9,26	5,00***
Heat flow downwards / $W \cdot m^{-2} \cdot K^{-1}$	6,13	5,00***
External heat convective – roof / $W \cdot m^{-2} \cdot K^{-1}$	29,30	25,00***
Inputs for specific test cases:		
South shading – case 610 and 910	Figure 2.11	Figure 2.11
East/west window orientation – case 620 and 920	Figure 2.12	Figure 2.12
Night ventilation – case 650 and 950	From 1800 to 0700 hours, ventilation = on From 0700 to 1800 hours, ventilation = off Heating = off From 0700 to 1800 hours, cool = on if T_a> 27 °C; Otherwise, cool = off	From 1800 to 0700 hours, ventilation = on From 0700 to 1800 hours, ventilation = off Heating = off From 0700 to 1800 hours, cool = on if T_a> 27 °C; Otherwise, cool = off

*Minimum possible U-value in TEKNOsim.
**Changes were in the thermal capacity of the construction, the overall U-value remained the same.
***Maximum possible value in TEKNOsim.

[1] Refers to the conditioned zone air temperature.
[2] Radiative portion of the internal heat gains cannot be defined in TEKNOsim. It is calculated in the algorithm as 100 minus % of convective potions.

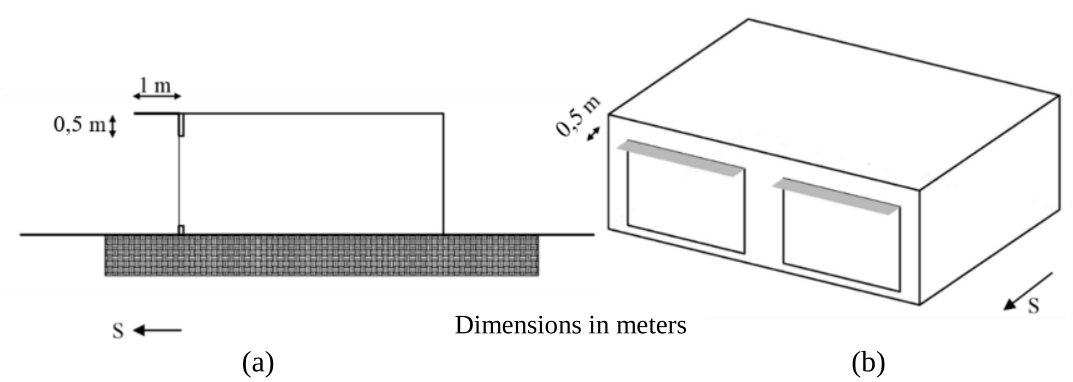

Figure 2.11: Geometry of the overhang for cases 610 and 910 as defined by (a) the Standard and (b) TEKNOsim.

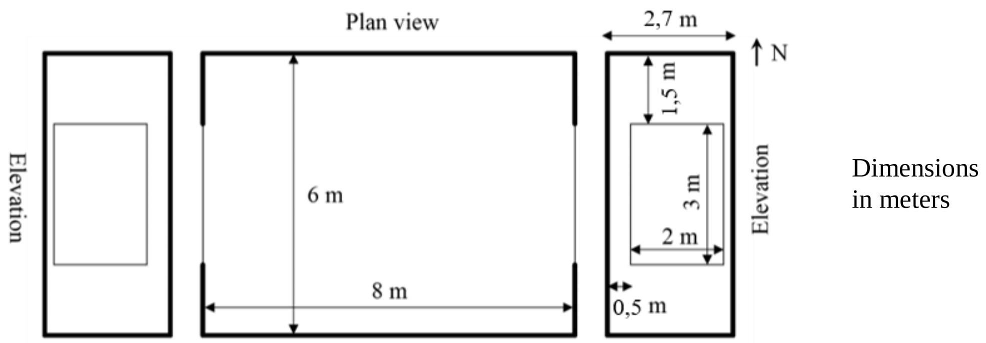

Figure 2.12: Layout of the east and west windows for cases 620 and 920.

As mentioned earlier in this Section, Table 2.6 shows the input data of the base test case, case 600, as well as different inputs for all cases in the Basic Tests category. Differences in some input values prescribed by the standard and used in TEKNOsim simulations were due to the limitations of the software to define their values. For test cases 610 and 920, the geometry of the shading device modelled by TEKNOsim was different than prescribed by the Standard. TEKNOsim solely considers the effect of the overhang structure that is directly projected over the window. Hence, the projection depth and height of the overhang were altered as shown in Figure 2.11. The Standard specifies that the overhang covers all the width of the south façade. Also, it has a depth of 1 m and is placed 0,5 m above the window. In TEKNOsim the projection depth was changed to 0,5 m, as can be seen from Figure 2.11 (b). Also, the overhang was projected exactly at the top of the window and had the same width as the window. This approximation was made according to the algorithm used in TEKNOsim for modelling the overhang shading. Cases 620 and 920 have east and west facing windows. These openings have the same properties of the window as given in Table 2.6. The orientation of the two openings was modified to the layout in Figure 2.12 to model cases 620 and 920, respectively. For simulating the peak heating loads, the winter outdoor temperature can be prescribed in TEKNOsim using one of the following two methods: 1) Based on the calculation of Swedish Standard SS 02 43 and 2) User provided value of the outdoor temperature. The first method takes the average temperature in January and using a mathematical formula converts it into an outdoor temperature. For this thesis, the second method was used and the outdoor temperature was always set to -24,4 °C. This value corresponds to the minimum dry bulb temperature in the Typical Meteorological Year (TMY) weather file provided by the Standard. For this thesis, it was also assumed that the peak heating load occurs at the minimum outdoor temperature.

2.2.3.2 Output requirements

The Standard requires comprehensive output results that could be compared with results from the other building simulation tools. These outputs include annual heating and cooling demands, peak heating and cooling loads, and annual hourly maximum, minimum and average zone air temperature for the free-float tests. For some specific cases, outputs such as annual incident solar radiation, annual transmitted solar radiation, and annual transmissivity coefficient of windows are also required. The outputs from TEKNOsim were obtained and compared against other simulation tools with certain modifications as discussed earlier. The outputs from TEKNOsim included:

- Annual integrated peak heating loads for the simulated cases.
- Annual integrated peak sensible cooling load for the simulated cases.
- Maximum annual integrated zone temperature for the free-float cases.

The minimum and average annual hourly zone temperatures cannot be calculated by TEKNOsim. This is because TEKNOsim only models the thermal loads and the thermal indoor environment during the peak summer and winter days. Moreover, annual hourly data could not be acquired from the software, though the hourly data of the dimensioning day were possible to obtain.

2.2.4 CIBSE TM33:2006

This Section includes “Tests for software accreditation and verification” by Chartered Institute of Building Services Engineers Standard. The CIBSE TM33 Standard comprises of three main categories. Each category has a different scope, purpose, and calculation procedure. The first category – General purpose tests, includes a series of test cases that are part of the National Calculation Methodology [25] to check the software’s internal quality assurance. The second category – Empirical validation test, demonstrates the ability of the software to reproduce measured data of an existing building. This test cannot be modelled in a simple software like TEKNOsim. Hence, it was excluded from this study. The last category – CIBSE Specific Tests, contains additional cases to perform the validation of the understudy software. Table 2.7 explains tests included in each category, together with their focus. It is also stated if a test was implemented in TEKNOsim or not.

Each test requires certain outputs from the program that should be within an acceptable tolerance range. For example, for test G2, solar azimuth and altitude of three different locations should be calculated for four local time sets. The overall outputs of each test and their corresponding acceptable tolerances are shown in Section 3.2.4.

Table 2.7 - Description of test cases included in CIBSE TM33:2006 Standard and their implementation in TEKNOsim.

Category	Test	Aim	Simulated in TEKNOsim
General purpose tests	Test G1: Databases	Test the ability of the program to define: building material thermal properties, climate data, and schedules for occupancy, ventilation, and loads	Yes
	Test G2: Solar position	Calculation of solar azimuth and altitude	Yes
	Test G3: Basic thermal calculations	Test the basic algorithm to calculate steady-state and transient response of different construction	Yes*
	Test G4: Solar shading	Shading effect of neighbouring buildings, awnings, and balconies	No. The objects cannot be modelled in TEKNOsim
	Test G5: Glazing properties	Calculation of g-value for typical glazing configuration	No. Not applicable in TEKNOsim algorithm
	Test G6: Steady state heat loss from rooms	Calculation of steady-state heat loss of a room	Yes**
	Test G7: Annual cooling and heating demand	Calculation of annual space heating and cooling	No. Energy demand cannot be calculated in TEKNOsim
	Test G8: Overheating risk	Internal temperature when there is no heating or cooling	No. Inability to input annual hourly climate data in TEKNOsim
	Test G9: Infiltration and ventilation	Impact of air flow on the thermal calculations	No. Tests require multiple zone simulations
	Test G10: Air handling unit test	Energy demand by heating and cooling coils and fans	No. TEKNOsim does not include component plant models
Empirical validation test	Empirical validation test	Reproduce measured data of space heating loads and air temperatures	No. TEKNOsim cannot model complex buildings with multiple cells
CIBSE-specific tests	Test C1: Solar position	Calculation of solar azimuth and altitude	Yes
	Test C2: Derived material properties	Derive properties of the construction for thermal calculations	Yes***
	Test C3: Derived glazing properties	Calculation of solar gain factors	No. Not possible in TEKNOsim
	Test C4: Psychrometric properties	Calculation of moisture content, enthalpy, and specific volume of air	No. Not possible in TEKNOsim
	Test C5: Cooling load	Calculation of design cooling load	Yes
	Test C6: Summertime temperature	Peak summertime temperatures	Yes
	Test C7: Interstitial condensation	Calculation of annual accumulative moisture and mass of condensed water	No. Not possible in TEKNOsim

*Test G3.2 was not included due to the requirement of daily output data which cannot be retrieved from TEKNOsim.
**Tests A2 and B2 were excluded as it was not possible to prescribe an emitter with 60 % convection in TEKNOsim.
***Results are compared against the construction transmittance only.

3 Results

3.1 Qualitative analysis

For the questionnaire discussed in Section 2.1 and presented in Appendix A, answers from respondents were gathered and Cronbach's alpha was calculated as shown in Figure 3.1. The variance for each question was calculated after inversing the Likert scale coding. The Likert scale was originally based on plain text statements. However, in order to perform a statistical analysis, it was converted into a numerical scale. Cronbach's alpha for Section B of the questionnaire was determined from Equation 1 and calculated to be to be 0,56. The interpretation of Cronbach's alpha reliability coefficient is presumed to be Excellent if $\alpha \geq 0{,}9$, Good if $\alpha \geq 0{,}8$, Acceptable if $\alpha \geq 0{,}7$, Questionable if $\alpha \geq 0{,}6$, Poor if $\alpha \geq 0{,}5$, and Unacceptable if $\alpha < 0{,}5$ [26]. The value of Cronbach's alpha is greatly influenced by the number of respondents. The calculated value of 0,56 of the Cronbach's alpha for the Section B of the questionnaire indicated a poor mean inter-correlation between respondents' replies. For Section C, the value of Cronbach's alpha was determined to be 0,72. This value indicated a collective agreement among the feedback of the respondents for the Section C.

After establishing the correlation between scores of Section B and Section C of the questionnaire, respectively, respondents replies were sorted and compiled to highlight the perceived strengths and weaknesses of TEKNOsim 5. The distribution of the respondents' disciplinary background is shown in Figure 3.2. It was interesting to comprehend how users' outlook and opinion on the software and its functions was influenced by their respective backgrounds. Nearly 72 % respondents had an engineering background, approximately 22 % had an architectural background, and the remaining 6 % had a mixed background in both architecture and engineering.

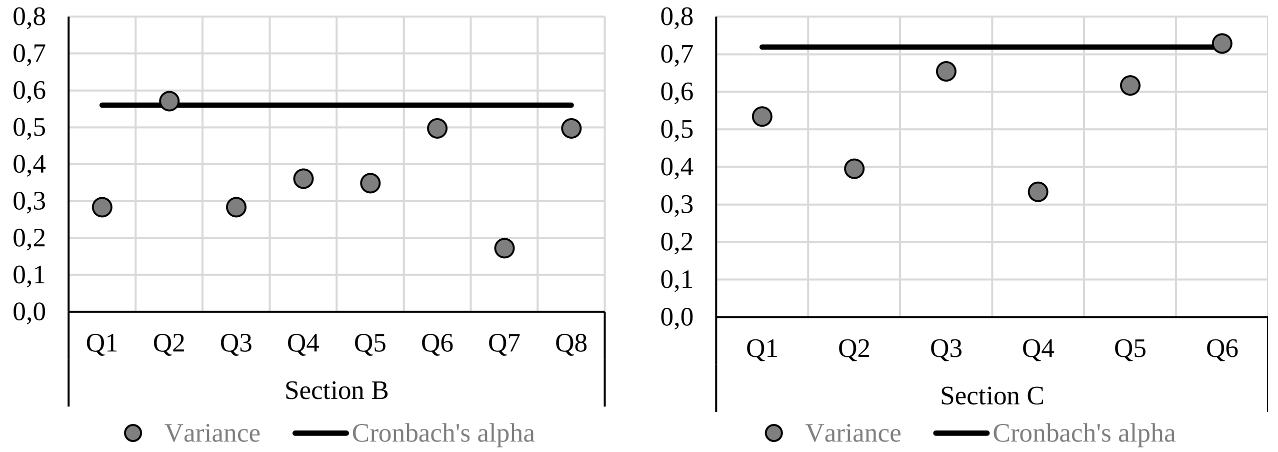

Figure 3.1: Variance and Cronbach's alpha for questions of Sections B and Section C of the questionnaire.

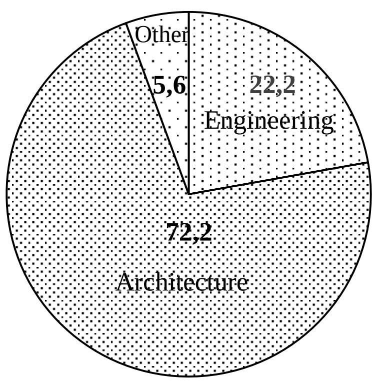

Figure 3.2: Respondents' disciplinary background.

Figure 3.3 illustrates respondents' expectations on the functionality of TEKNOsim before working with the program. It also indicates the HVAC system type simulated as their design task by respondents. Half of the respondents correctly identified TEKNOsim as an indoor thermal climate simulation tool. About 17 % of the students wrongly classified TEKNOsim as a building energy simulation software. The remaining respondents characterised TEKNOsim as a tool for simulation of mechanical equipment. Their answers cannot be categorized as totally "correct" or "incorrect" as TEKNOsim does has an option to select a variety of Lindab® products. However, the core of the question was to select the most appropriate function of the TEKNOsim software from the provided options. For their design exercise, all respondents used TEKNOsim to design a Constant Air Volume (CAV) cooling system. Approximately 22 % of the respondents also dimensioned ventilation and zone heating systems, in addition to the CAV cooling system.

Figure 3.4 summarizes respondents' views on basic features of the program inquired in Section B of the questionnaire. The majority of the respondents agreed that TEKNOsim 5 has a well-developed database and provides extensive libraries of weather data, mechanical systems, and building components. However, approximately, 26 % of respondents had a different opinion on the database of the TEKNOsim 5. The ability to add new components to the database was regarded as a time consuming process. The respondents' response indicated that they would prefer an even larger databse with more predefined building components. The other five statements shown in Figure 3.4 had a wide discrepancy between respondents' feedback, which also explains the poor reliability coefficient for this Section. A large number of the respondents also agreed that TEKNOsim has a short learning curve period. The graphical visualization of the new interface was perceived as user-friendly with an easy to follow structure and a simple navigation through the interface.

Nearly, 44 % of the students perceived that results provided by TEKNOsim 5 are not accurate. This perception could be based on the fact that all respondents had previously worked with complex building energy simulation programs before using TEKNOsim 5. The modelling experience in TEKNOsim 5 is quite different to any other complex building energy simulation software. The time and inputs required to build and run a simulation are considerably reduced compared to more complicated programs. This simplicity of the tool could be the reason behind the repondents' perception of TEKNOsim being not so accurate. More than half of the respondents were not satisfied with the amount of information offered by the help files. However, the program version provided to the respondents was a test version for testing the software algorithm with the new interface. This version did not include the help files added later in the final version of TEKNOsim 5. This explains the poor feedback upon the help files.

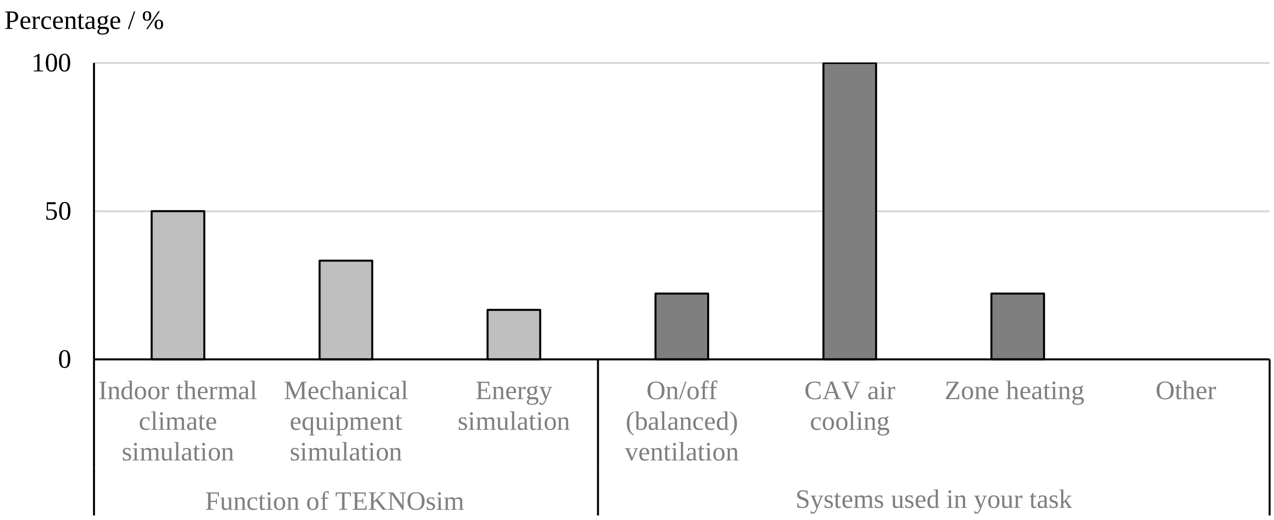

Figure 3.3: Respondents' feedback on TEKNOsim 5 functions, and system types modelled by them.

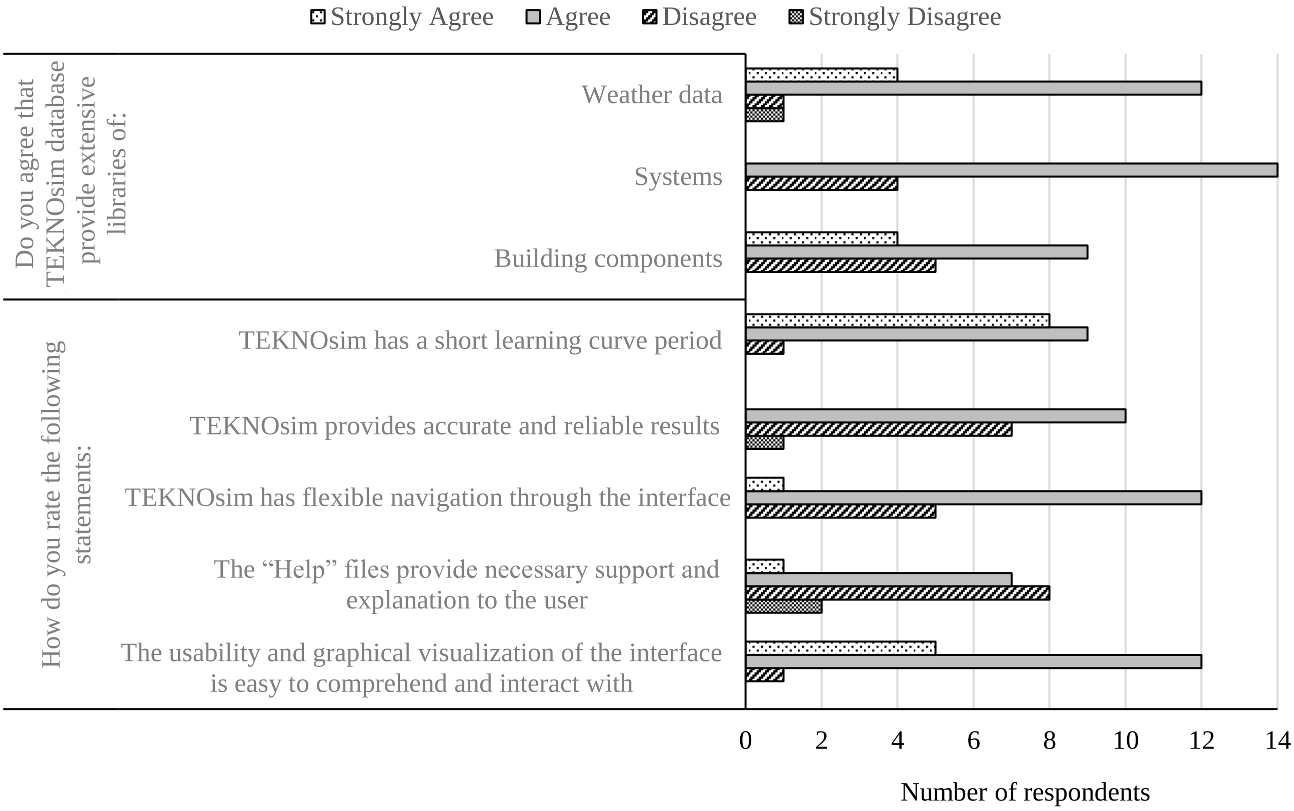

Figure 3.4: Respondents' feedback on basic features of TEKNOsim 5 from Section B of the questionnaire.

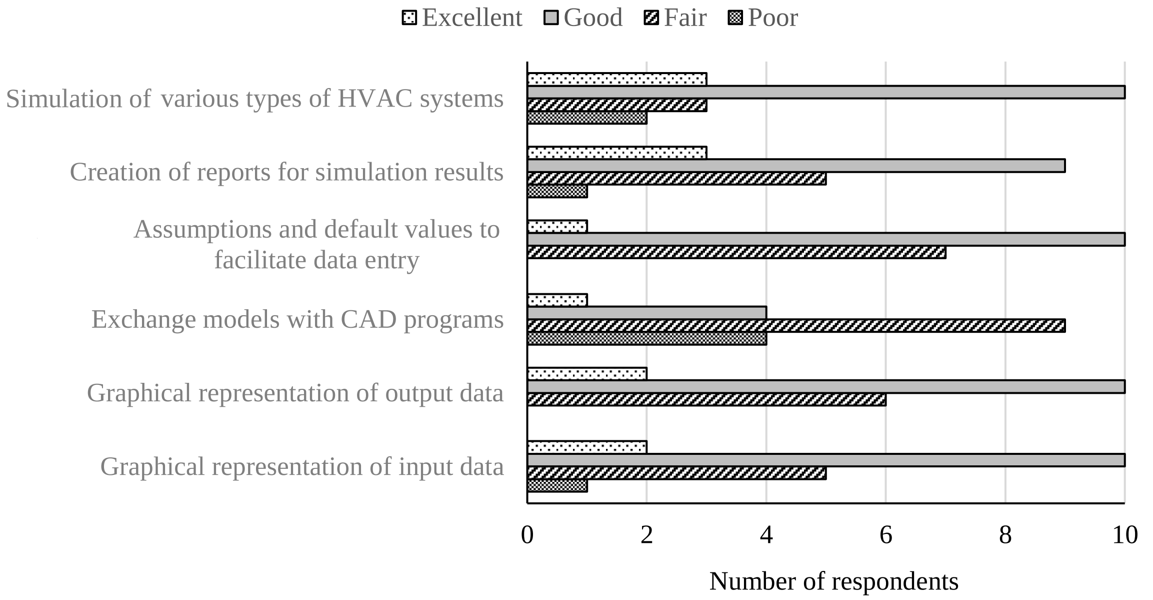

Figure 3.5: Respondents' feedback on basic features of TEKNOsim from Section C of the questionnaire.

Section C of the questionnaire was intended to investigate users' opinion on in-depth features of the program. Results of reliability coefficient calculations for Section C are shown in Figure 3.1. Respondents' replies are summarized in Figure 3.5. Features related to the simulation of various HVAC systems, the graphical representation of input and output data, and the use of default values suggested by the program were all ranked favourably between fair to good. The only feature that had an overall negative feedback was the ability of the program to exchange models with CAD programs. This feature, which has been recently added to the version 5 of the software, requires a plug-in to make the exchange possible with the CAD programs. The respondents may not have found enough information on this feature.

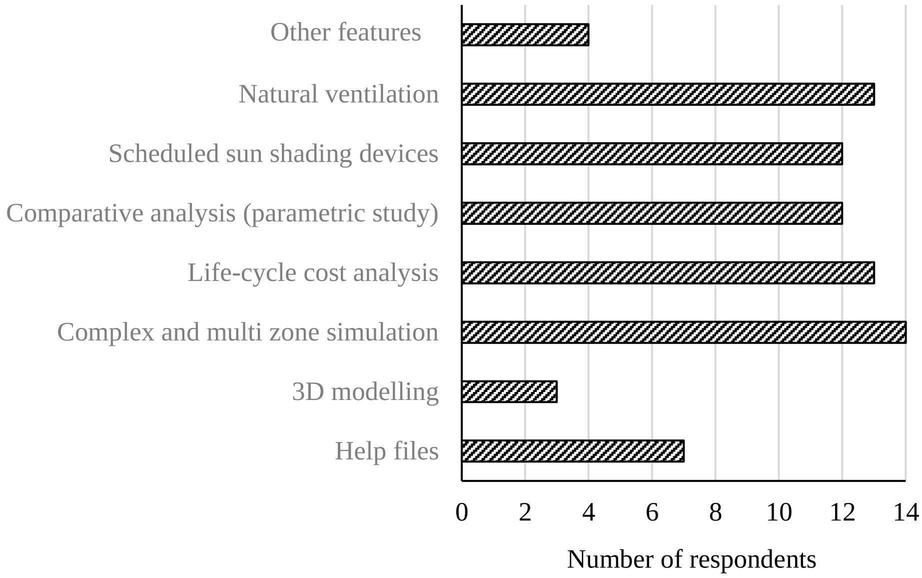

Figure 3.6: Respondents' inputs on features should be improved or added in the future developments of TEKNOsim.

Respondents' inputs on features that should be added or improved in the future development of the TEKNOsim program are shown in Figure 3.6. One feature that was suggested by all respondents was the ability of the program to model and simulate multi-zone buildings. The inclusion of features on natural ventilation and life-cycle cost analysis were ranked second by the respondents. Features including comparative analysis and implementation of scheduled sun shading devices were ranked third among the options to be considered in the future development of the software. Three other features were suggested by the respondents on their own. These included: 1) Provision of more detailed output than thermal loads, 2) Inclusion of psychrometric analysis, and 3) Possibility to turn off CAV system for prescribed time operation.

3.2 Quantitative analysis

3.2.1 EN ISO 13791:2012

Results of the 18 test cases of EN 13791, discussed in Section 2.2.1, are shown in Figures 3.7. The results have been obtained for different number of peak days. The number of peak days refers to the consecutive number of days for which the simulated building is assumed to be influenced by peak ambient conditions. As can be seen from the figure, the discrepancy of is TEKNOsim results is larger than the limits prescribed by the Standard when three peak days are considered. A positive value of the deviation indicates that TEKNOsim has underestimated the operative temperature, which is used as a measure of the indoor thermal climate. The deviation between TEKNOsim output and the Standard's limits is decreased with increasing number of total simulated days (peak days). The heat accumulation in the zone is increased when the peak conditions occur for a longer consecutive period. The percentage of results that fall within the limits prescribed by the Standard is 37, 22, 27 and 30 % for three, five, seven and nine number of peak days, respectively. Although the percentage of results within the prescribed limits is lower for peak days equal to nine than peak days equal to three, but the deviation in TEKNOsim and Standard results is minimum for peak days equal to nine. When nine peak days are considered, the largest observed discrepancy between TEKNOsim results and Standard limits is 8 %. On the other hand, peak days equal to three give a discrepancy of 17 %. This can also be visually interpreted by looking at the box plot in Figure 3.7, where the top error bar represents the maximum value, the two boxes in the middle corresponds to the results of 50 % of the cases included in each test, the line that separates the two boxes shows the median of the results, and the bottom error bar shows the minimum value. For peak days equal to nine, the median of maximum, average, and minimum operative temperatures is confined within the range deemed acceptable by the Standard. The largest deviation is observed for minimum temperature, which falls 2,1 K outside the acceptable range. Based on these findings, from here onwards, all test cases for different standards included in this thesis have been simulated with a fixed number of peak days equal to nine.

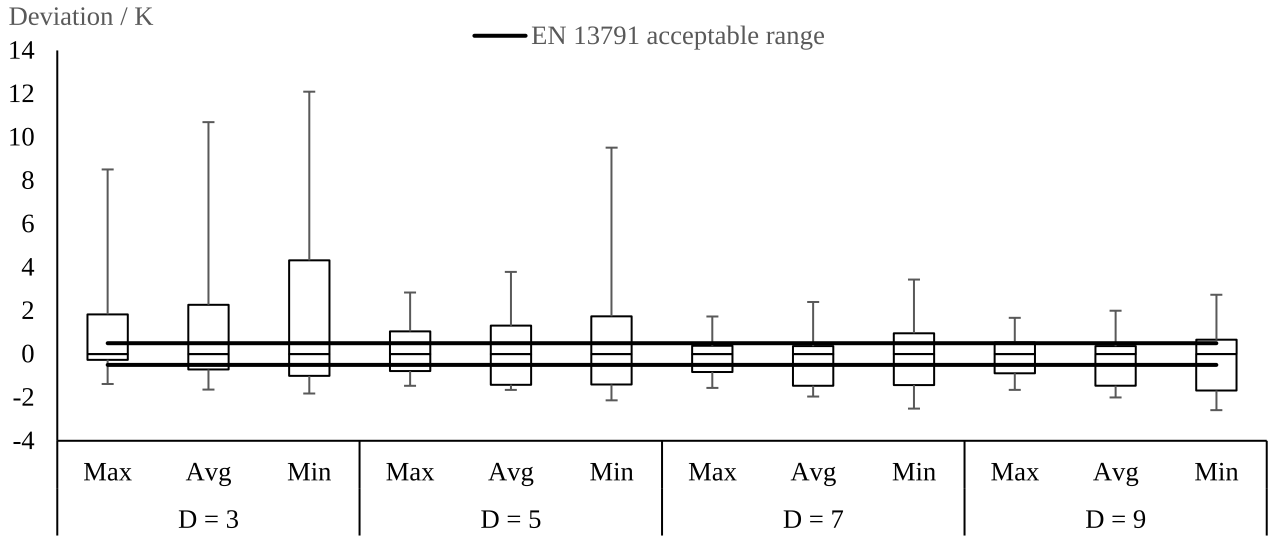

Figure 3.7: Deviation of operative temperature between EN 13791 and TEKNOsim for geometry considering different number of peak days.

3.2.2 EN 15255:2007

The discrepancy between TEKNOsim 5 results and limits prescribed by EN 15255 are presented in Figure 3.8 for nine cases described in Section 2.2.2. The results obtained from TEKNOsim indicate that the software overestimates the operative temperature in the zone (i.e. +2 K for Test 4). Results of three out of the nine test cases are within the limits prescribed by the Standard. The maximum difference between EN 15255 and TEKNOsim results is seen in test cases four and nine. For both these cases, a double pane (DP) glazing was used. These two cases had a deviation of +2 K, whereas the acceptable range provided by the Standard is ± 0,5 K. This deviation corresponds to 6 % higher operative temperatures from TEKNOsim 5. The higher values of operative temperature calculated from TEKNOsim 5 are related to higher inputs of outdoor temperatures and solar radiation (see Figures 2.7 and 2.8), which influence the heat storage inside the building envelope.

As seen from Figure 3.9, almost 50 % results of maximum and average cooling loads calculated from TEKNOsim for the dimensioning day are within the limits set by the Standard. The largest deviation of the average cooling load is 14 % for Test 4. On the other hand, TEKNOsim 5 gives a higher estimation of the average cooling load during the dimensioning day for seven out of the nine test cases. TEKNOsim over predicts the value of the maximum cooling load in four cases. The largest deviation of the maximum cooling power is 13 % for Test 3.

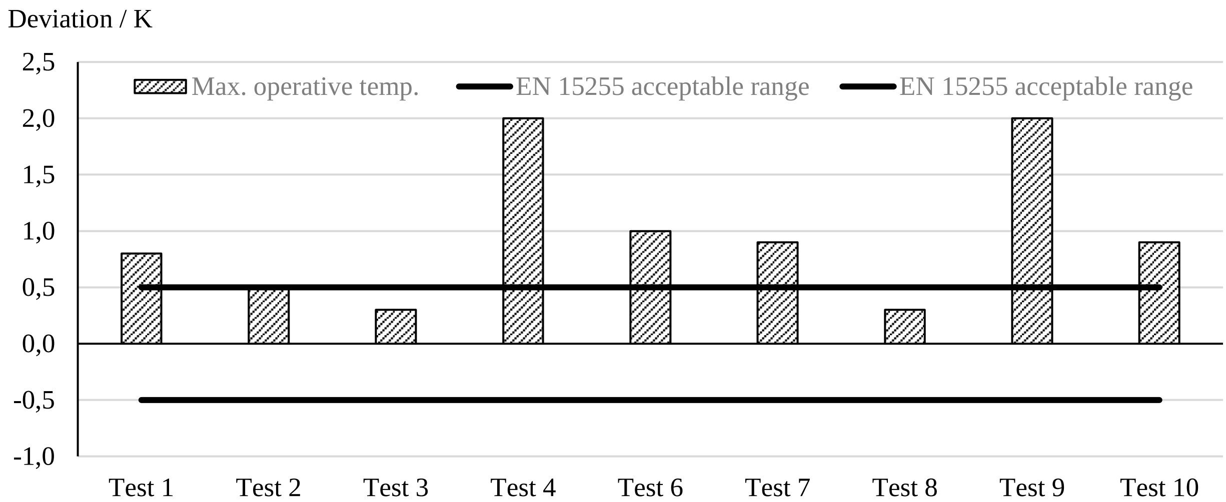

Figure 3.8: Deviation of operative temperatures between EN 15255 and TEKNOsim 5 for simulated Test cases.

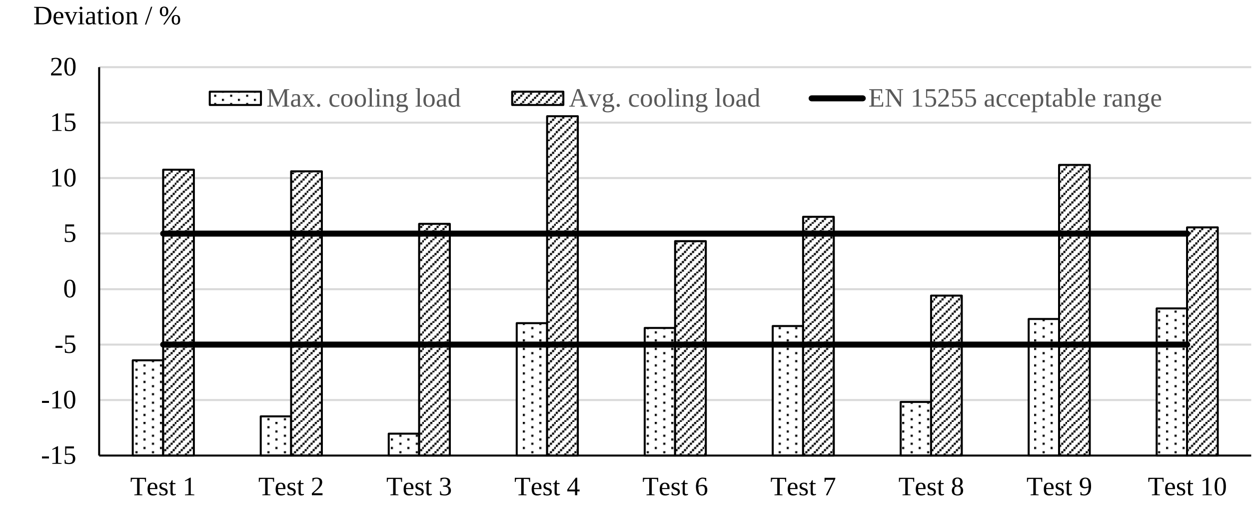

Figure 3.9: Deviation of maximum and average cooling loads between EN 15255 and TEKNOsim 5 for simulated cases.

3.2.3 ANSI/ASHRAE 140-2011

This Section presents comparison results between different building energy simulation tools and TEKNOsim as discussed in Section 2.2.3.1. Figure 3.10 shows comparative results of peak heating loads determined by TEKNOsim 5 for the Basic Tests against other simulation tools that participated in BESTEST. In addition, results from IDA-ICE and DesignBuilder for the same test cases are also presented. Cases 650 and 950 had no heating load as the heating system is assumed to be turned off. TEKNOsim 5 results for the lightweight cases (i.e. tests 600, 610, and 620) are within the range of maximum and minimum results from the other simulation tools. For heavyweight cases, i.e. tests 600, 610, and 620, TEKNOsim gives same results as for corresponding lightweight construction. This is because TEKNOsim 5 assumes worst-case scenario when calculating the peak heating loads, which means specific heat capacity of the structure does not influence the calculation. As can be seen from Table 2.6, the thermal conductance of construction envelopes is same for both light- and heavyweight cases. In addition, TEKNOsim 5 also disregards the solar gains when modelling winter conditions to simulate the worst-case scenario of the peak heating load. The largest difference between TEKNOsim 5 and the mean result of the other seven participated program is equal to 12 % for case 900.

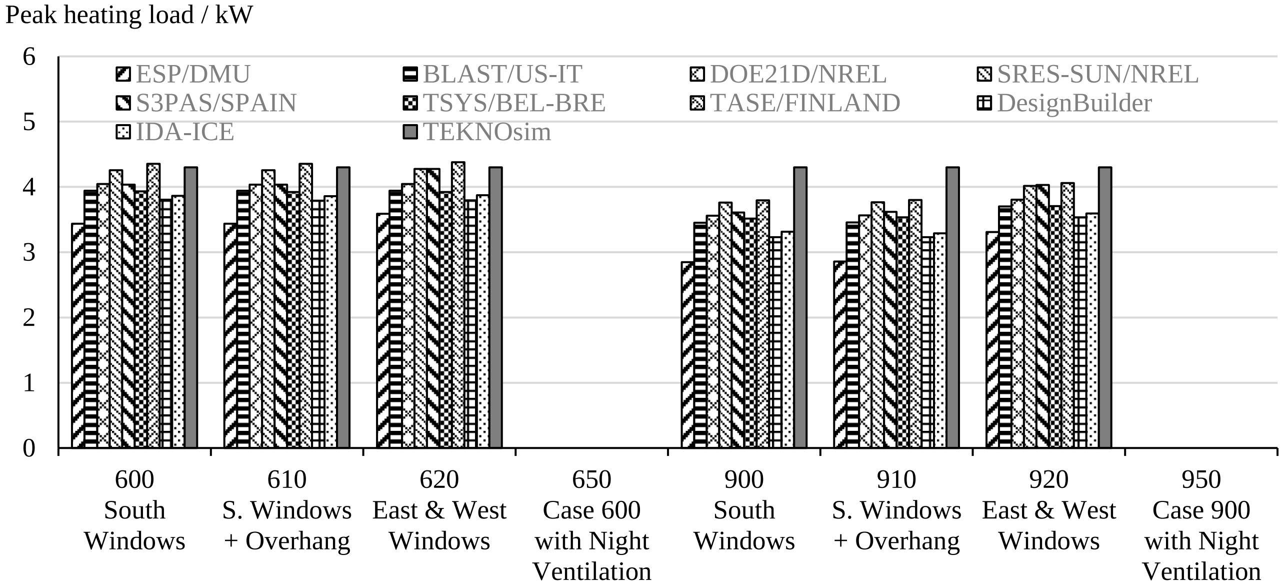

Figure 3.10: Comparison of peak heating loads for Basic Tests from ANSI/ASHRAE 140 Standard.

The comparison of TEKNOsim 5 peak sensible cooling loads with BESTEST programs, and IDA-ICA and DesignBuilder are shown in Figure 3.11. TEKNOsim 5 results are in general within the range of mean peak cooling loads determined from the other simulation tools. However, there exist some differences for test cases 610, 650, 900, and 920. Case 610 has an overhang shading. TEKNOsim 5, as discussed in Section 2.2.3.1, cannot model the overhang prescribed by the standard. Hence, some changes were introduced to the overhang geometry. However, it is apparent that for solar altitudes prescribed by the Standard, the modified geometry of the overhang is hindering the solar radiation through the window. Hence, TEKNOsim 5 calculates the peak cooling load to be approximately 24 % lower than from the other simulation tools. Case 650 is with night ventilation. For this test case, TEKNOsim 5 underestimates the mean peak cooling loads by approximately 5 % compared to the minimum values from the other simulation tools. This can be explained by the differences in hourly outdoor temperatures used in TEKNOsim and as prescribed by the Standard. In TEKNOsim, Case 900 resulted in higher peak cooling load. The difference was about 4 % compared to the maximum values of other simulation tools. Case 920 is with windows at the east and the west sides. For this case, TEKNOsim 5 calculates the peak cooling load to be approximately 7 % higher than the maximum values from the other tools. Figure 3.12 presents a comparison of thermal indoor climate for Free-Float tests discussed in Section 2.2.3.1 in terms of the maximum zone air temperature. The agreement of TEKNOsim 5 results with other simulation tools is notable for all four test cases. The results from TEKNOsim 5 always lie within the range of maximum and minimum results from the other simulation tools. Nevertheless, the results of the ANSI/ASHRAE 140-11 cannot be interpreted or taken as the acceptance criteria [18]. Each software has its own limitations and algorithms. It is clearly visible from Figures 3.11 and 3.12 that some programs either overestimate or underestimate the results in comparison to other programs. For example, the majority of IDA-ICE results suggest a higher peak sensible cooling load as well as a higher zone air temperature than other simulation tools.

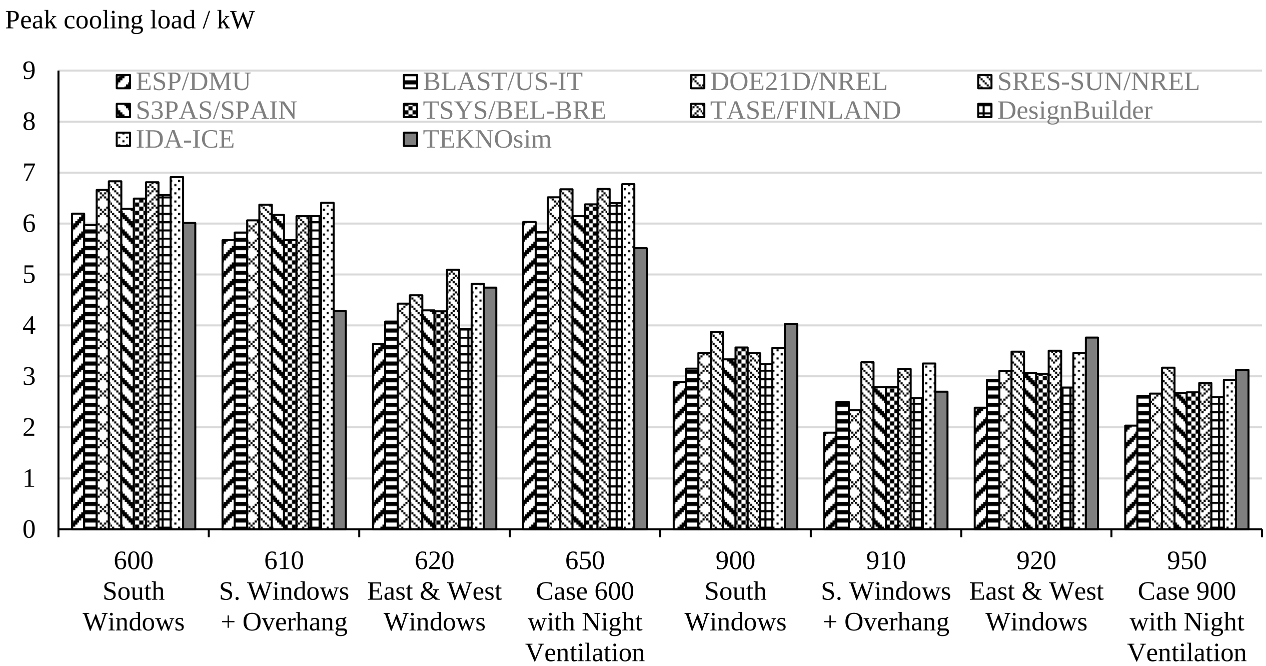

Figure 3.11: Comparison of peak sensible cooling loads for Basic Tests from ANSI/ASHRAE 140 Standard.

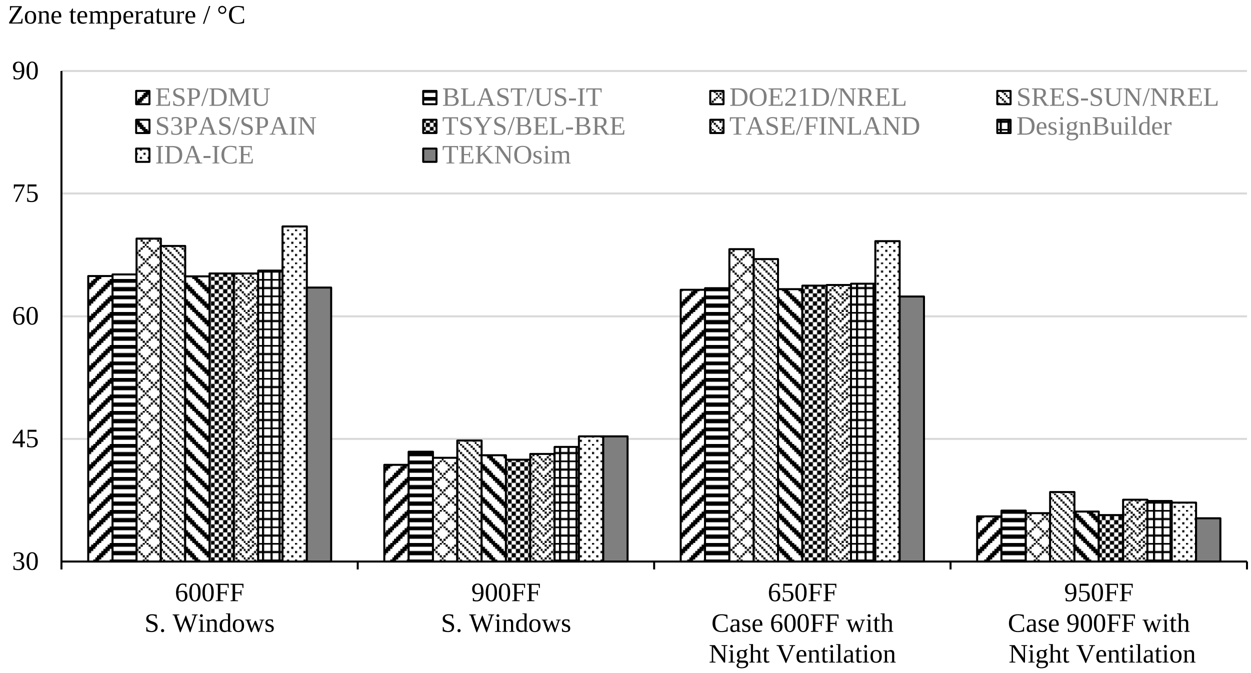

Figure 3.12: Comparison of zone air temperatures for Free-Float Tests from ANSI/ASHRAE 140 Standard.

3.2.4 CIBSE TM33:2006

3.2.4.1 General purpose tests

This category of tests aims to evaluate a program's ability to define thermal properties of building materials. The results for TEKNOsim 5 are reported in Table 3.1 to Table 3.7. For General purpose test G1A, the Standard provides a list of construction materials and their related thermal properties including a) densities, b) thermal conductivities, and c) specific heat capacities. TEKNOsim 5 provides the user with an option to edit the program's database, hence enabling them to define any construction material according to their requirement. Table 3.1 shows the reference values from the Standard compared to the values defined in TEKNOsim 5. As can be seen from the table, the user is able to accurately define the characteristics of the building's material according to the given specifications.

Table 3.1 - Results of Test G1A: Building material thermal properties.

Material	Density / $kg \cdot m^{-3}$		Thermal conductivity / $W \cdot m^{-1} \cdot K^{-1}$		Specific heat capacity / $J \cdot kg^{-1} \cdot K^{-1}$	
	Reference	TEKNOsim	Reference	TEKNOsim	Reference	TEKNOsim
Outer brick	1700	1700	0,840	0,840	800	800
Cast concrete	2000	2000	1,130	1,130	1000	1000
Medium weight concrete	1800-2000	1800-2000	1,150-1,650	1,150-1,650	1000	1000
Mineral fiber	30	30	0,035	0,035	1000	1000
Expanded polystyrene	25	25	0,035	0,035	1400	1400
Plywood sheathing	530	530	0,140	0,140	1800	1800
Timber board	300-1000	300-1000	0,090-0,240	0,090-0,240	1600	1600
Asbestos cement	700	700	0,360	0,360	1000	1000
Brick inner leaf	1700	1700	0,560	0,560	1000	1000
Carpet	20	20	0,058	0,058	1000	1000
EPS 50mm	15	15	0,040	0,040	1300	1300
Sandstone	2600	2600	2,300	2,300	1000	1000
Brick	1800	1800	0,990	0,990	850	850
Masonry	1600	1600	0,790	0,790	850	850
Cement screed	2000	2000	1,400	1,400	850	850
Concrete	2400	2400	2,100	2,100	850	850
Timber	650	650	0,150	0,150	1600	1600
Insulation 1	30	30	0,040	0,040	850	850
Insulation 2	50	50	0,040	0,040	850	850
Plaster 1	1400	1400	0,700	0,700	850	850
Plaster 2	900	900	0,210	0,210	850	850
Covering	1500	1500	0,230	0,230	1500	1500
Acoustic tile	400	400	0,060	0,060	840	840
Tiles	1500	1500	0,230	0,230	1300	1300
Glass	2500	2500	1,060	1,060	1000	1000

The second test in the General purpose tests is the climate data test, which examines the ability of a program to define climate data. Reference values for the city of London have been provided by the Standard for the design day of July 15 for a reference year. Comparison of outdoor temperature, and global horizontal and diffused radiation provided by the Standard and calculated from TEKNOsim 5 is provided in Table 3.2. The Standard does not set any value or range of acceptable accuracy. As explained earlier in Section 2.2.1, when implementing the equations used for calculating hourly solar radiation and outdoor temperature, deviations in the climate data can be observed between the values provided by CIBSE Standard TM33 and obtained from TEKNOsim 5. The outdoor temperatures from TEKNOsim do not have a large deviation compared to the Standard. On the other hand, the values of global horizontal radiation and diffused radiation provided by TEKNOsim are almost two times higher and around 45 % lower than the values suggested by the Standard, respectively.

Table 3.2 - Results of Test G1B: Climate data.

Hour	Temp / °C		Solar radiation / W·m^{-2}			
			Global (horizontal)		Diffused	
	Reference	TEKNOsim	Reference	TEKNOsim	Reference	TEKNOsim
1	14,0	11,6	0	0	0	0
2	13,3	11,1	0	0	0	0
3	12,2	11,0	0	0	0	0
4	11,0	11,1	0	0	0	0
5	11,5	11,6	30	0	20	0
6	12,1	12,2	155	62	54	52
7	13,2	13,1	332	196	131	89
8	15,1	14,1	420	367	98	107
9	16,9	15,2	619	542	110	116
10	17,8	16,3	385	699	269	122
11	17,5	17,3	239	824	231	125
12	18,3	18,2	379	906	360	127
13	19,2	18,8	610	938	409	128
14	19,1	19,3	336	919	334	128
15	19,4	19,4	287	849	279	126
16	18,9	19,3	218	734	216	123
17	18,8	18,8	238	584	235	118
18	18,8	18,2	110	412	104	110
19	18,0	17,3	35	237	35	94
20	17,0	16,3	2	90	1	64
21	13,4	15,2	0	7	0	7
22	13,0	14,1	0	0	0	0
23	12,9	13,1	0	0	0	0
24	12,8	12,2	0	0	0	0

Table 3.3 - Results of Test G1C: Loads and schedules.

Hour	Fraction of maximum for stated schedule							
	Zone 1		Zone 2		Zone 3		Zone 4	
	Reference	TEKNOsim	Reference	TEKNOsim	Reference	TEKNOsim	Reference	TEKNOsim
0_1	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00
1_2	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00
2_3	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00
3_4	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00
4_5	0,25	*0,50*	0,00	0,00	0,00	0,00	0,00	0,00
5_6	0,50	0,50	0,00	0,00	0,00	0,00	0,00	0,00
6_7	0,50	0,50	0,00	0,00	0,00	0,00	0,00	0,00
7_8	0,50	0,50	0,00	0,00	0,10	0,00	0,50	*0,00*
8_9	0,50	0,50	0,00	0,00	0,25	0,25	0,75	*1,00*
9_10	0,50	0,50	0,25	*0,00*	0,25	0,25	1,00	1,00
10_11	0,50	0,50	0,50	*0,00*	0,10	*0,25*	1,00	1,00
11_12	0,50	0,50	0,50	*0,00*	0,10	*0,25*	1,00	1,00
12_13	0,25	*0,50*	0,25	0,25	0,25	0,25	0,50	0,50
13_14	0,25	*0,50*	0,25	0,25	0,25	0,25	0,50	0,50
14_15	0,25	*0,50*	0,50	0,50	0,10	0,10	1,00	1,00
15_16	0,25	*0,50*	0,50	0,50	0,10	0,10	1,00	1,00
16_17	0,50	0,50	0,50	0,50	0,10	0,10	1,00	1,00
17_18	0,50	0,50	0,00	0,00	0,10	0,10	0,50	*1,00*
18_19	0,50	0,50	0,00	0,00	0,00	0,00	0,00	0,00
19_20	0,50	0,50	0,00	0,00	0,00	0,00	0,00	0,00
20_21	0,50	0,50	0,00	0,00	0,00	0,00	0,00	0,00
21_22	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00
22_23	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00
23_24	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00

The last General purpose test in the database test cases is intended to assess the approach used by a software to define the daily occupancy schedule of the simulated building. Daily schedules of four different space activities including an airport (zone 1), a court lecture (zone 2), a university staff room (zone 3), and a workshop (zone 4) are shown in Table 3.3. The values in the table present the fraction of maximum people intensity in the space. Due to the limitation of TEKNOsim 5 to define a load schedule with more than two time periods, slight modifications were made in the load schedule prescribed by the Standard. The cells italic text in the Table show the fraction values that have been adjusted in TEKNOsim. In total, 13 out of the 96 hourly fractions have been altered and adjusted.

Test G2 focuses on the calculation of solar position for three different locations in terms of their solar azimuth and altitude. Table 3.4 shows the coordinates of all three locations and the time of interest used for the calculation. The comparison of results provided by the Standard and determined by TEKNOsim are also shown in Table 3.4. The acceptable tolerance for this test is ± 1,5° from the values provided by the Standard. All results from TEKNOsim are within the acceptable tolerance limits for both solar azimuth and altitude.

Table 3.4 - Results of Test G2: Solar position.

Time (hh/dd/mm)	London 51,48 N / 0,45 W				Manchester 53,25 N / 2,27 W				Edinburgh 55,95 N / 3,35 W			
	Azimuth / °		Altitude / °		Azimuth / °		Altitude / °		Azimuth / °		Altitude / °	
	Ref.	TS	Ref.	TS	Ref.	TS	Ref.	TS	Ref.	TS	Ref.	TS
1200/22/12	180,0	179,9	15,1	15,1	178,3	178,3	13,3	13,3	177,3	177,3	10,6	10,6
1500/27/02	224,1	223,8	20,4	19,8	221,9	221,6	19,9	19,3	220,2	220,0	18,3	17,7
1200/21/06	178,4	178,4	62,0	61,9	175,2	175,2	60,1	60,1	173,7	173,7	57,4	57,4
1000/20/10	151,1	151,5	24,4	23,0	149,6	150,0	22,3	20,9	149,1	149,4	19,7	18,3

Test G3 is intended to evaluate the approach used by a software to calculate the thermal transmittance. The results of the static conduction test are presented in Table 3.5. The maximum acceptable tolerance for all construction types is ± 1 % of the values provided by the Standard. All TEKNOsim 5 results, except for internal wall 2, lie within the acceptable tolerance limits. Also, it was not possible to obtain results for window 1 and window 2 from TEKNOsim 5. This is because in TEKNOsim the U-value of the window construction is an input and is defined by the user.

Table 3.5 - Results of Test G3.1: Static conduction test.

Construction	Transmittance / $W \cdot m^{-2} \cdot K^{-1}$	
	Ref.	TEKNOsim
External wall	0,49	0,49
Internal wall 1	0,35	0,36
Internal wall 2	1,68	*1,98*
Floor	0,24	0,24
Ceiling	0,23	0,24
Roof	0,44	0,44
Window 1	2,94	N/A
Window 2	1,72	N/A

The last series of tests, Test G6, included under the General purpose tests are related to steady state loss from zones, and surface and air temperatures. These tests are intended to demonstrate the surface temperature, air temperature, and heat loss through the construction fabric of a room. The methodology that TEKNOsim uses for the calculation of surface temperatures is described below. The surface temperature of a building element, T_{sur} in °C is determined by the following formula, where T_I is the room desired temperature in °C, X_{sur} is the dimensionless resistance of the surface, and T_{DIM} is the temperature difference between the ambient environment and the inner side of the surface in Kelvins (K).

$$T_{sur} = T_I X_{sur} + (1 - X_{sur}) T_{DIM} \quad (21)$$

The dimensionless resistance factor formula for windows, X_w, is different than any other construction. For windows, it is calculated from the following formula, where U_w is the window U-value in ($W \cdot m^{-2} \cdot K^{-1}$), and R_i is the internal contact resistance (equals to 0,1 $m^2 \cdot K \cdot W^{-1}$).

$$X_w = \frac{1}{1 + \frac{1}{\frac{1}{U_w R_i} - 1}} \tag{22}$$

The dimensionless resistance factor of other constructions, X_{sur}, is calculated from the following formula, where R_a presents the inner accumulative heat resistance of the structure, and R_e is the heat resistance of the structure from accumulative layer to outside. Values of R_i, R_a, and R_e depend on the construction type e.g. facade, roof, inner wall, etc.

$$X_{sur} = \frac{1}{\frac{R_i}{R_a + R_e} + 1} \tag{23}$$

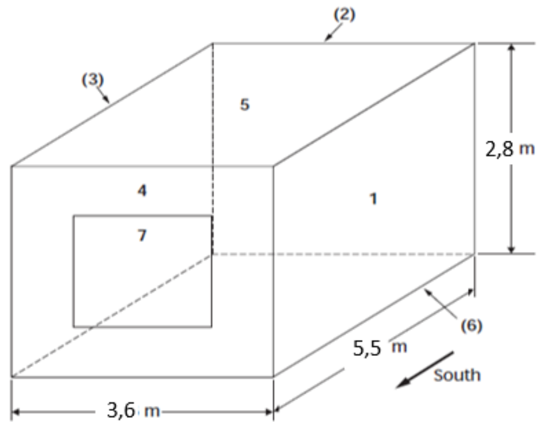

Figure 3.13: Isometric view of the room geometry and surface number for test G6.

Figure 3.13 shows the room layout used for the test together with the surface number used in Table 3.6. The acceptable tolerance limits for the results of Table 3.6 is 0,2 K, whereas the acceptable tolerance limits for the heat loss shown in Table 3.7 is ± 2,5 %.

Table 3.6 - Results of Test G6: Steady state loss from rooms surface and air temperature.

Test	Model	Temperature of stated surface / °C							Air temp / °C
		1	2	3	4	5	6	7	
A1	Reference	20,50	20,60	20,50	19,40	20,90	20,20	11,10	22,20
	Basic	20,60	20,60	20,60	19,00	20,90	20,10	11,10	22,20
	Simple	This method is not recommended for calculation of surface temperatures							22,10
	TEKNOsim	*20,96*	*20,96*	*20,96*	19,51	20,98	*20,97*	*13,65*	*21,00*
A2	Reference	20,80	21,00	20,80	19,70	20,90	20,80	11,20	21,30
	Basic	20,90	20,90	20,90	19,40	21,00	20,80	11,20	21,30
	Simple	This method is not recommended for calculation of surface temperatures							21,30
	TEKNOsim	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
B1	Reference	20,20	19,00	19,00	19,20	20,80	19,70	11,00	22,80
	Basic	20,30	18,90	18,90	18,90	20,80	19,60	10,90	22,80
	Simple	This method is not recommended for calculation of surface temperatures							22,60
	TEKNOsim	*20,96*	*19,51*	*19,51*	*19,51*	20,98	*20,97*	*13,65*	*21,00*
B2	Reference	20,90	19,60	19,50	19,80	21,00	20,90	11,30	21,20
	Basic	20,90	19,50	19,50	19,40	21,00	21,00	11,20	21,20
	Simple	This method is not recommended for calculation of surface temperatures							21,10
	TEKNOsim	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

The surface temperatures obtained from TEKNOsim 5 have in general higher values than provided by both reference and basic models. The italics text in Table 3.6 refers to the results that lie outside the tolerance limits. The largest deviation between TEKNOsim 5 and basic model results is for window surface in Test B1 and equals 2,75 K. As Test B1 simulates winter periods, the air temperature considered by TEKNOsim 5 is the same as the desired indoor temperature defined by the user.

Table 3.7 presents results of steady state heat loss from rooms. As can be seen, TEKNOsim results fulfil the specified tolerance limits of 2,5 %. The deviation is slightly larger when TEKNOsim 5 results are compared to the reference or basic models. However, as the Standard gives an option to compare the results against any of the three models, it is reasonable to assert that TEKNOsim results pass the acceptable tolerance limits.

Table 3.7 - Results of Test G6: Steady state loss from rooms.

Test	Model	Heat loss / W			Test	Model	Heat loss / W		
		Fabric	Infiltr-ation	Total			Fabric	Infiltr-ation	Total
A1	Reference	542	121	663	B1	Reference	831	496	1327
	Basic	541	121	662		Basic	830	496	1326
	Simple	568	120	688		Simple	860	491	1352
	TEKNOsim	577	114	691		TEKNOsim	883	457	1340
A2	Reference	556	117	673	B2	Reference	862	465	1327
	Basic	554	117	671		Basic	859	465	1324
	Simple	574	117	690		Simple	877	464	1342
	TEKNOsim	N/A	N/A	N/A		TEKNOsim	N/A	N/A	N/A

3.2.4.2 Specific tests

This category of tests requires that the program being tested shall report the output of Test G1A: Building material thermal properties. The test results from TEKNOsim 5 and reference CIBSE method are shown in Table 3.1. The first test in this category, Test C1, is similar to Test G2 from the General purpose tests category and is aimed to calculate the solar position for different locations. This test, however, uses different locations. The results from TEKNOsim 5 and the reference values prescribed by CIBSE TM 33 shown in Table 3.8. As was the case with Test G2, all results from TEKNOsim 5 are within the acceptable tolerance limits for both solar azimuth and altitude.

For test C5, Cooling load, results for air temperature control have been obtained from TEKNOsim since it has only two control methods for calculating cooling loads: a) Air temperature control, or b) Operative temperature control. The simulated model for this test is similar to the model used in EN 15255 as discussed in Section 2.2.2. The peak and average cooling loads are required as an output of this test with ± 10 and 5 % tolerance limits, respectively. The output of TEKNOsim shows that the peak cooling load is within the provided tolerance limits for all tests, whereas the mean peak cooling load is outside the acceptable range for each test. The highest deviation of the mean cooling load is 20 % related to Test C5.4, see Table 3.9.

Table 3.8 - Results of Test C1: Solar position.

Time (hh/dd/mm)	Auckland (+12) 37,02 S / 174,8 E				Cairo (+2) 30,13 N / 31,4 E				Reykjavik (-1) 64,13 N / 21,9 W			
	Azimuth / °		Altitude / °		Azimuth / °		Altitude / °		Azimuth / °		Altitude / °	
	Ref.	TS	Ref.	TS	Ref.	TS	Ref.	TS	Ref.	TS	Ref.	TS
1200/22/12	18,1	18,2	75,8	75,8	182,1	182,0	36,4	36,4	174,1	174,1	2,3	2,3
1500/27/02	301,7	301,1	46,3	46,8	234,1	233,6	33,5	33,0	215,3	215,2	12,9	12,3
1200/21/06	5,8	5,8	29,3	29,3	188,1	188,4	83,2	83,3	169,8	169,9	49,0	49,0
1000/20/10	54,3	55,8	50,9	51,9	145,5	146,4	43,4	42,1	146,8	147,0	11,8	10,4

The last test, i.e. Test C6, uses the same model as Test C5, but with different input data. Results of this test shall include maximum, average, and minimum operative temperatures of the zone for the prescribed summer design day of July 15. The results should lie within – 1,5 K to + 2 K of the reference values provided by the Standard. The results of test cases C6.1 to C6.6 are shown in Table 3.10. The cases are different from each other on the basis of construction types and air changes per hour. For example, Tests C6.5 and C6.6 have a non-adiabatic roof construction instead of an adiabatic ceiling. Also, the air changes per hour vary between one and ten for every second case. Overall, 38 % of TEKNOsim results lie within acceptable limits of CIBSE results. As seen from Table 3.10, the largest deviation in Test C6.4 is for minimum operative temperature and equals 4,3 K.

Table 3.9 - Results of Test C5: Cooling load.

Test	Air temperature control				Dry resultant control			
	Peak / W		Mean / W		Peak / W		Mean / W	
	Ref.	TEKNOsim	Ref.	TEKNOsim	Ref.	TEKNOsim	Ref.	TEKNOsim
C5.1	1592	1536	565	*624*	1837	N/A	571	N/A
C5.2	1363	1233	565	*622*	1691	N/A	571	N/A
C5.3	3554	3360	1230	*1362*	4239	N/A	1260	N/A
C5.4	1677	1604	547	*436*	1837	N/A	571	N/A
C5.5	3917	3488	1143	*989*	4530	N/A	1218	N/A

Table 3.10 - Results of Test C6: Summertime temperatures.

Test	Max operative temp. / °C		Mean operative temp. / °C		Min operative temp. / °C	
	Ref.	TEKNOsim	Ref.	TEKNOsim	Ref.	TEKNOsim
C6.1	35,4	*33,2*	30,4	29,4	27,0	25,9
C6.2	28,1	29,9	21,5	*24,6*	16,6	*19,8*
C6.3	33,3	*31,2*	30,4	29,2	28,4	27,6
C6.4	26,2	27,2	21,5	*24,6*	17,9	*22,2*
C6.5	34,5	*30,6*	31,5	*28,3*	29,4	*26,3*
C6.6	27,1	27,4	22,3	*24,5*	18,6	*21,8*

4 Discussion and conclusions

This Section discusses the interpretation, analysis and diagnosis of the results of TEKNOsim 5 with a specific focus on their quality and on the algorithmic processes used for the simulations of thermal loads and thermal indoor environment. The new interface of the software is discussed based on the feedback of users, who had the opportunity to test and work with the new version. The evaluation of program's computational methods was carried out to highlight the main sources of deviations between TEKNOsim 5 and other analytical and comparative verification procedures.

4.1 Features of TEKNOsim 5

The new version of TEKNOsim 5 software comes with extensive changes in the interface and graphical presentation of both input and output data. The survey conducted on the sample of users has been aimed to obtain their input on the new interface and features of the software. The 3D modelling window has been introduced for the first time in the new version of the software. This feature enables using a set of drawing tools to build up a model by exploiting the basic drafting options. The compatibility of TEKNOsim 5 to import and export drawings with CAD programs has been perceived as a time-consuming process by the users due to the requirement of installing plugins to make the exchange of drawings possible. Nevertheless, this feature drastically decreases the required time to build a new model from scratch. The navigation through different windows and tabs has been perceived as extremely easy and user-friendly by the sample of users. This feature goes well with the main objective of the software to model and simulate a building zone without significant modelling effort and ample time requirements. The ability of the software to export simulation results in different types of formats has been perceived as incoherent and vague by most of the users. This highlights the need of providing detailed and more explanatory help files.

The existing database in TEKNOsim gives the user an option to select predefined data related to weather, building components, and other inputs used in simulations. In addition, the user can define their input data in case the database does not provide them with their precise input conditions. Also, as observed and reported by the users, the help files in the test version of TEKNOsim 5 were not updated and did not provide users with enough information. The users, to some extent, found it difficult to comprehend the meaning and function of some inputs required by the program. The help files were also missing specific definitions of these inputs. A more comprehensive explanation of these inputs would have helped users to fully understand the input parameters before defining them in the program. The help files in the test version of TEKNOsim 5 were initially phrased and compiled based on the old version of the software, which contributed to the negative feedback and the general perception of help files being insufficient and uninformative. New help files that are compatible and applicable with the new interface have been designed by the author of this thesis and have been integrated in the final release version of the software.

The respondents of the survey have a collective agreement on some features that should be added to the software to enhance its functionality and usage. The possibility to model and simulate multi-zone and complex buildings in TEKNOsim is given the highest score among the features that should be added to the software. Such a function will make TEKNOsim an excellent tool for quick estimations of thermal loads and thermal indoor environment during the early design stage of a project without the need of dividing the building into single zones. Another feature, which respondents have suggested to be added to TEKNOsim, is the possibility of carrying out a life-cycle cost (LCC) analysis of different Lindab's® HVAC products of indoor thermal environment to analyse their effect on the economic feasibility of the overall system.

4.2 Diagnosis of TEKNOsim 5 results

The simplicity in defining the input data in TEKNOsim entails a few adaptations in the simple inputs augmented by TEKNOsim algorithm to perform a simulation. The simple inputs defined by the user, are transformed by the TEKNOsim algorithm to obtain more detailed parameters required to run the simulated model. For example, as discussed in Section 2.2.1.1, TEKNOsim calculates the hourly outdoor air temperature for the design day based on the limited information provided by the user. The user inputs related to ambient climate data, internal loads and schedules, thermal storage through the building components, and the heat generation or extraction within the conditioned zone are all adjusted and transformed by the software algorithm. A series of analytical and comparative verification tests have been performed in this thesis to test the accuracy of the algorithm used in TEKNOsim and to compare the results of the program in relation to other building energy simulation tools.

As discussed earlier in Section 2.2.1.1, the simple approach that TEKNOsim follows in estimating the weather conditions at the site location has a significant impact on the incident solar radiation and the outdoor temperature fluctuation over the design day. Therefore, a sensitivity analysis has been made to minimize the discrepancy of climate data. The analysis includes optimization of both the peak temperature hour and atmospheric transmissivity values. Despite making these corrections, the user cannot get the exact outdoor temperature and solar radiation profiles. Instead, somewhat similar climate profiles will be calculated by the software. However, it is recommended to optimize the values of peak temperature hour and atmospheric transmissivity in accordance to the methodology prescribed in Section 2.2.1.1. This will give a fairly decent match between the model and TEKNOsim climate conditions, hence reducing the discrepancy.

The operative temperature is one of the most significant parameters that has been calculated by TEKNOsim and compared against reference values in different Standards. The Standards used in this study define the operative temperature as the arithmetic mean of the air and the mean radiant temperature. On the other hand, TEKNOsim calculates the operative temperature based on several factors. As shown in Equation 20 in Section 2.2.1.3, these factors include the activity level and the clothing degree of the occupant, in addition to the indoor air speed. However, in this study the effect of these factors has been eradicated while obtaining the operative temperature values from TEKNOsim according to the stated method in Section 2.2.1.3. Nevertheless, the users are advised to pay attention to these factors while performing simulations in TEKNOsim. The accurate description of the indoor conditions yields reliable interpretation of the calculated operative temperature.

The calculation of thermal loads and the thermal indoor climate in TEKNOsim 5 is strongly related to the type of the product used for the provision of heating and cooling. TEKNOsim provides users with two options to select the type of mechanical cooling and heating products while performing simulations. First option is to select one of the Lindab’s products, and the second is to select a generic all-air mechanical equipment. For all type of simulations used in this study, the generic all-air system with constant air volume using 100 % convective air and infinite capacity has been used. This option provides a fair comparison between TEKNOsim results and the reference values provided by the Standards. Test cases that require certain cooling systems, such as chilled ceiling, have not been included in this study. Even though it is possible to simulate a chilled ceiling system in TEKNOsim, the results are difficult to compare against the provided reference values. The reason behind this is that the Standards use hypothetical characteristics of the simulated chilled ceiling system. On the other hand, simulating one of Lindab’s chilled ceiling products is related to the physical and actual technical data of a real product. Therefore, the simulated case will never have the same conditions as prescribed by the Standards.

The modelling of an overhang shading system in TEKNOsim has its own limitations. For some cases, the geometry of the overhang must be modified according to the prescribed method in Section 2.2.3.1. These modifications include changes in the width and the depth of the overhang projection above the window. TEKNOsim can only model an overhang that is directly placed above the window. At the same time, the overhang cannot be wider than the window. Subsequently, modifying the geometry of the overhang is essential for the calculations of solar gains. However, this may still result in differences between the calculated solar gains from TEKNOsim and other building energy simulation tools.

4.3 Impact of outdoor temperature

Throughout the scope of this thesis, it was noticed that defyning hourly temperature profiles in TEKNOsim is not straight forward. Therefore, differences between outdoor temperatures of the model and temperature profile calculated by TEKNOsim can be observed. These differences have a significant impact on the results of TEKNOsim. In order to eleminate this uncertainty, a special beta version of TEKNOsim was provided by Lindab. The beta version could accept hourly temperature values to accurately define the design day conditions. This version was intended for internal testing to analyze the impact of defining hourly temperature profile on the calculated results from TEKNOsim. The test cases provided by all Standards in this study were also simulated in TEKNOsim beta version. Test cases in Standards EN 13791, EN 15255, and CIBSE TM33, all provide a 24-hour temperature profile, where these test cases are simulated for one design

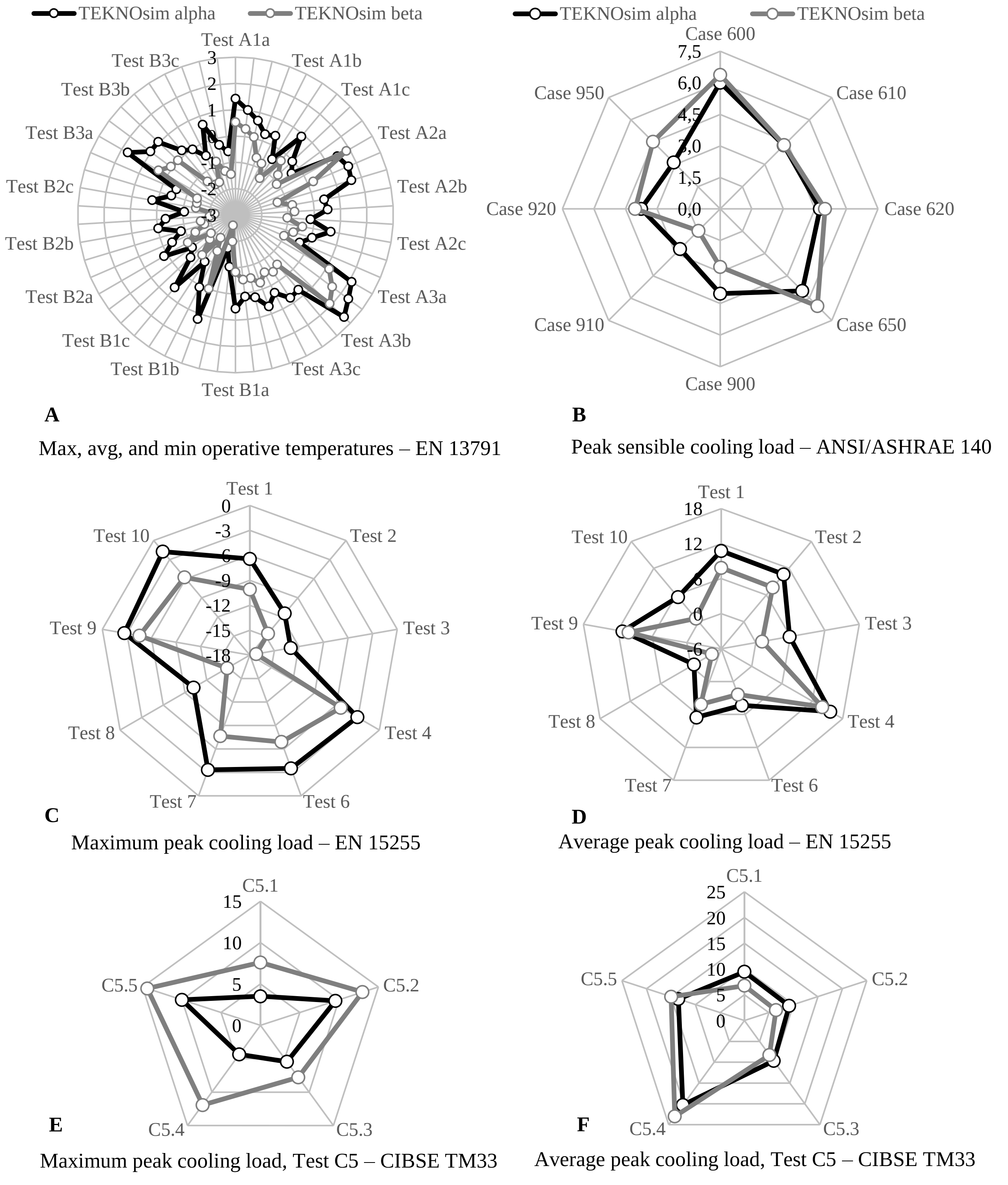

Figure 4.1: Comparison of results of TEKNOsim 5 alpha and beta versions with standard and hourly input climate data, respectively.

day (July 15). On the other hand, ANSI/ASHRAE Standard 140 provides an annual weather file (TMY) to prescribe the climate data. The design day in this case has been selected by analyzing the results of BESTEST programs. These results include the design day at which the peak cooling load occurs. Hence, the 24-hour temperature profile that corresponds to the peak day has been obtained from the TMY file and defined in TEKNOsim beta. Figure 4.1 shows comparison of results between TEKNOsim alpha and beta version for the simulated test cases of each Standard. Chart A in Figure 4.1 shows that TEKNOsim beta provides operative temperatures that are more closer to the values prescribed by the Standard. For these test cases, the acceptable limit is ± 0,5 K. It can be clearly seen that TEKNOsim beta calculates more accurate results compared to TEKNOsim alpha. The same trend is also found in the results of peak and average cooling loads for EN 15255, as seen in Chart C and Chart D. Furthermore, Chart B indicates that the results of TEKNOsim beta are also more closer to the average results from the other simulation tools. This can be more clearly seen when comparing results in Chart B against results in Figure 3.11 in Section 3.2.3. Only two simulated cases in TEKNOsim beta provide results with discripancies larger than the average from the other simulation tools. These are cases 920 and 950, which consider east and west windows and night ventilation, respectively, for the heavyweight cases. Chart E and Chart F show the maximum and average peak cooling load results of Test C5 in CIBSE TM33 for both TEKNOsim alpha and beta. When the results of TEKNOsim beta are compared against reference values shown in Table 3.9 in Section 3.2.4.2, it becomes clear that TEKNOsim beta results are more closer to the provided results by the Standard.

A holistic analysis of the results presented in Figure 4.1 suggests that the results of TEKNOsim beta are more accurate when compared to reference values given by the Standards. The results tend to improve when the exact outdoor temperature profile is defined in TEKNOsim. However, the accuracy of the results in the thesis even further when the exact outdoor temperatures and solar radiation profiles are both provided for the simulations.

4.4 Conclusions

Simplified building energy simulation tools do not necessarily provide results with significant discrepancies compared to more advanced programs. Nevertheless, users are advised to comprehend the way these tools conduct and perform mathematical deductions in their algorithm. Each simulation tool has its own limitations that can have a drastic influence on the simulation results. Therefore, testing the accuracy of a program's algorithm by implementing verification procedures is crucial for both users and software developers. These verification procedures help to identify sources of errors that can be corrected to make the tool more accurate and dynamic.

The new version of TEKNOsim enhances the interactive process between the user and the software. The new interface simplifies the navigation process through different windows and tabs. It is highly recommended that the future development TEKNOsim shall include the feature of multi-zone simulations. Also, the possibility of estimating the life-cycle costing of Lindab's products can help increasing the user base of the program. Such a feature also makes it possible to distinguish between products in terms of their technical characteristics and economic feasibility.

The testing of algorithm used in TEKNOsim 5 has proved that the software is a reasonably reliable tool for making quick indoor thermal climate simulations in the early design stage of a project. The simplicity of defining inputs and of building up a model are two unique features of TEKNOsim. The software is perceived as a user-friendly simulation tool with a short learning curve. This makes TEKNOsim interesting not only for the experts in the building services sector, but also for the new users who are taking their initial steps in this field. The accuracy of TEKNOsim results for the indoor thermal climate is prominent in all of the simulated cases. The maximum deviation of indoor operative temperatures has been observed to be less than 2,7 Kelvin in comparison to reference values. Differences between the model conditions and the simulated model in TEKNOsim have only a marginal influence on the steady-state calculations of the indoor climate.

The dimensioning of peak cooling and heating loads in TEKNOsim is substantially related to the heat gains and losses through the building envelope. Differences in parameters, including climate data, internal heat gains, and thermal capacity of the construction entail deviations in peak cooling and heating loads between TEKNOsim and test cases from the Standards. Deviations of thermal loads compared to reference values tend to increase when the simulated cases require extensive input data that TEKNOsim cannot provide. Assumptions and simplifications to model these cases in TEKNOsim can be carried out with reasonable accuracy. The overall discrepancies between TEKNOsim results and the reference values are decreased when the exact outdoor temperature profile is defined in TEKNOsim. The features of defining hourly outdoor temperatures and solar radiation are strongly recommended to be added to the software due to their major impact on the simulation results.

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Appendix

Appendix A – Questionnaire for TEKNOsim 5

Section A:

Q1. What is your disciplinary background?

○ Architecture. ○ Engineering. ○ Other.

Q2. Before you have started working with TEKNOsim, you expected it to be used for:

○ Energy simulation.

○ Mechanical equipment simulation.

○ Indoor thermal climate simulation.

○ Other.

Q3. What kind of system/s have you used in TEKNOsim?

☐ On/off (balanced) ventilation.

☐ CAV air cooling.

☐ Zone heating.

☐ Other.

Q4. Please write down your name and email address in case we want to contact you.

Section B:

How do you rate the following statements:

	Strongly Disagree	Disagree	Agree	Strongly Agree
The usability and graphical visualization of the interface is easy to comprehend and interact with.	○	○	○	○
The "Help" files give all the support and explanation to the user.	○	○	○	○
TEKNOsim has flexible use and navigation.	○	○	○	○
In your opinion, did TEKNOsim provide accurate and reliable results?	○	○	○	○
TEKNOsim has a short learning curve period.	○	○	○	○

TEKNOsim database provides an extensive library of:

	Strongly Disagree	Disagree	Agree	Strongly Agree
1. Building components.	○	○	○	○
2. Systems.	○	○	○	○
3. Weather data.	○	○	○	○

Section C:

How do you rank the following features in TEKNOsim 5:

	Poor	Fair	Good	Excellent
Graphical representation of input data.	⬭	⬭	⬭	⬭
Graphical representation of output data.	⬭	⬭	⬭	⬭
Exchange models with CAD programs.	⬭	⬭	⬭	⬭
Allowing assumptions and default values to facilitate data entry.	⬭	⬭	⬭	⬭
Creation of reports for simulation results.	⬭	⬭	⬭	⬭
Support various types of HVAC systems.	⬭	⬭	⬭	⬭

Section D:

What other features should be improved/added in the future development of TEKNOsim?

☐ Help files.

☐ 3D modelling.

☐ Complex and multi zone simulation.

☐ Life-cycle cost analysis.

☐ Comparative analysis (parametric study).

☐ Scheduled sun shading devices.

☐ Natural ventilation.

☐ Other.

Appendix B – Summer simulation report of case A.1.a in EN 13791

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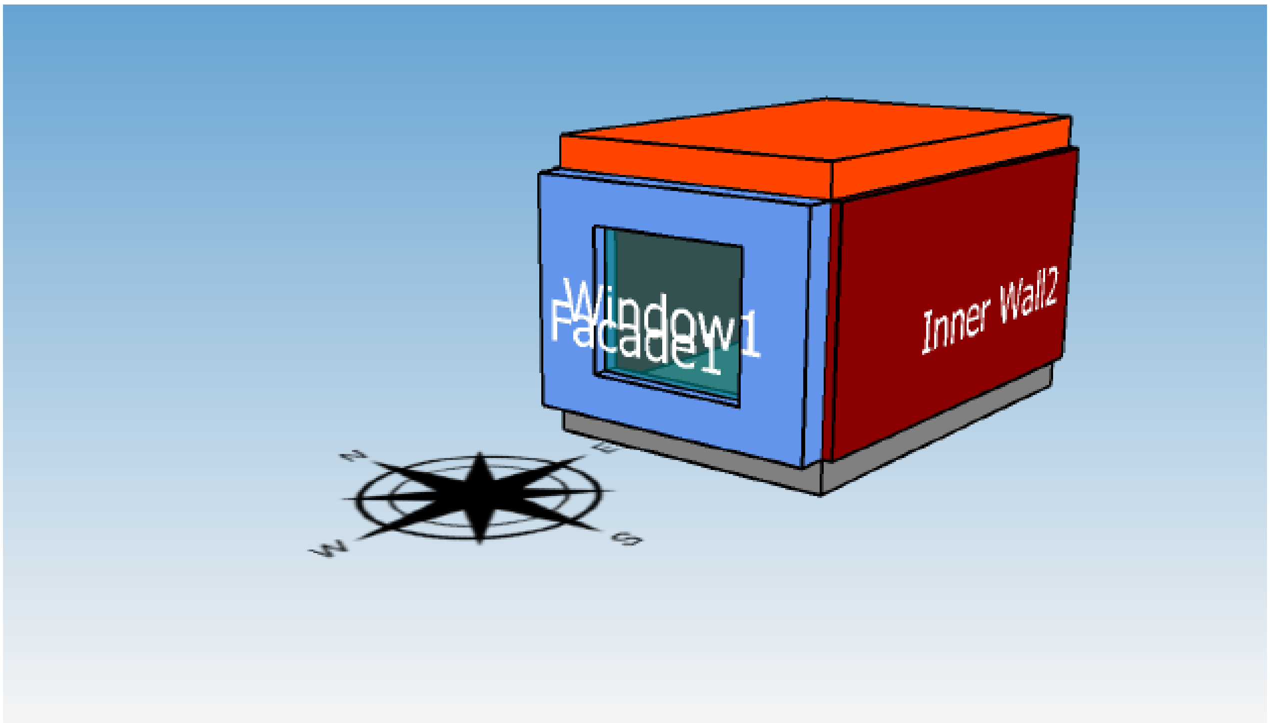
Summer Simulation:Type 1

Project Details			
Project Name	spaces	Map	Sverige
Building Name		City	EN 13792 - A
Internal Reference		Latitude [°]	40
External Reference		Longitude [°]	0
Comments			
Created From	marwan	Date	06-May-2016



Room Elements

Type	Name	Area [m²]	Construction	U-Value [W/m² K]	Thermal Capacity [J / kg K]	Direction [°]	Roof Angle [°]	Shading Factor
Facade	Facade1	10,1	External wall Type 1	0,50	37,10	270(W)		
Window	Window1	3,5	Single	3,58				
Inner Wall	Inner Wall1	10,1	Inner wall Type 2	0,36	2,60			
Inner Wall	Inner Wall2	15,4	Inner wall Type 2	0,36	2,60			
Inner Wall	Inner Wall4	15,4	Inner wall Type 2	0,36	2,60			
Floor	Floor1	19,8	Floor Type 4f	0,24	30,80			
Ceiling	Ceiling1	19,8	Cieling Type 4c	0,24	1,00			

1 of 3

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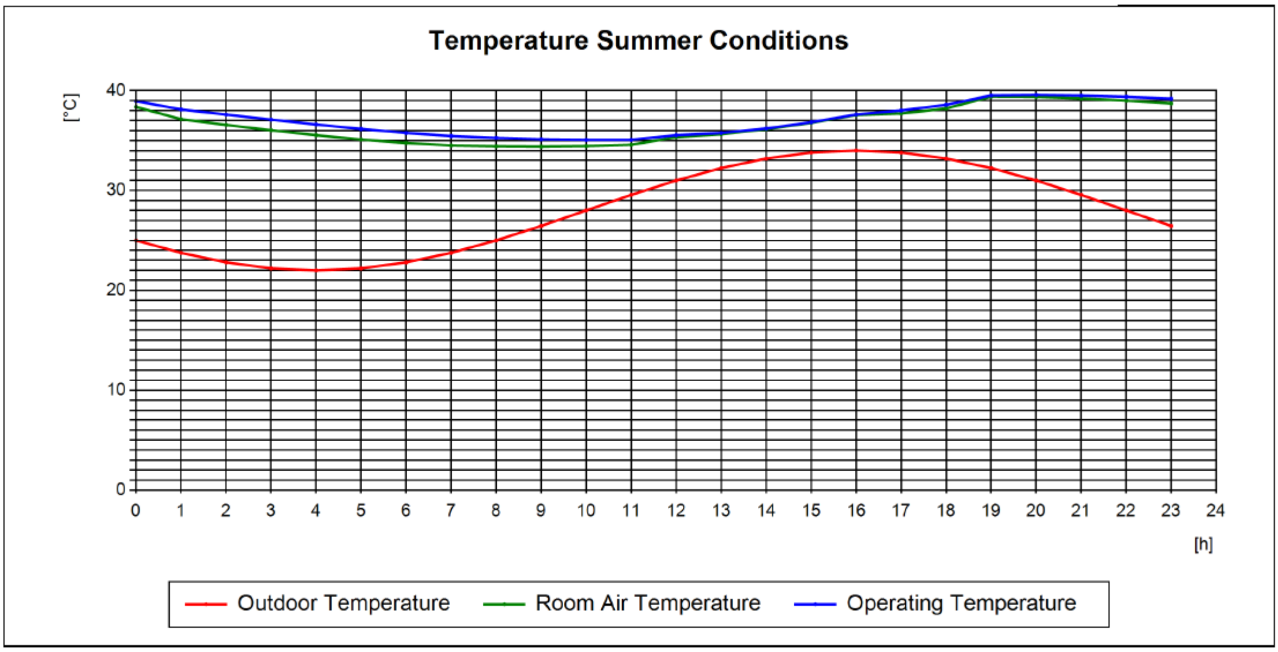

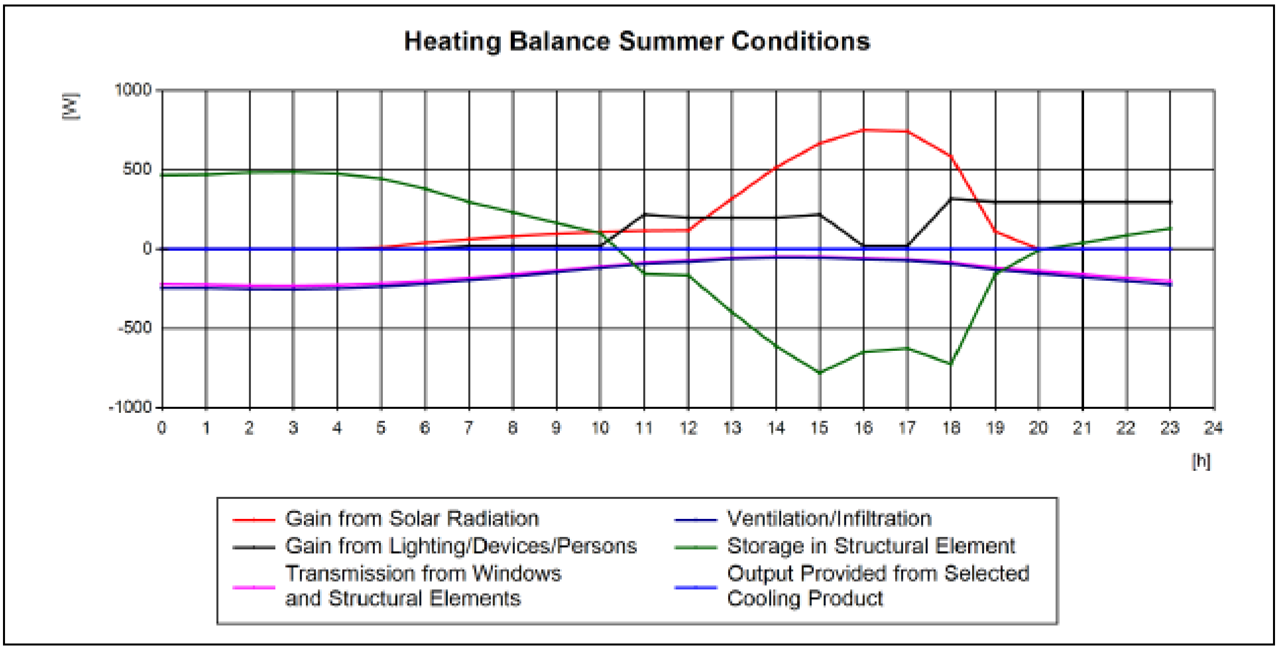

2 of 3

TEKNOSim Europe 5.0-Beta-1 [Testing]

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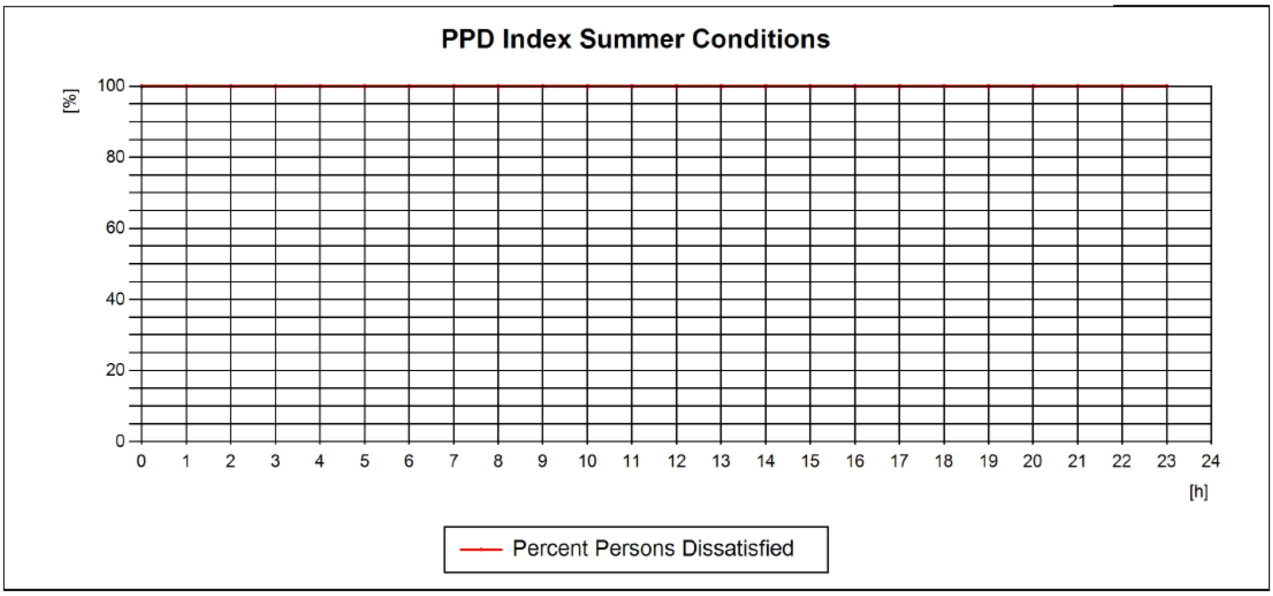

Summer Conditions		
Description	**Value**	**Time Point**
Max. Room Temperature	39,4 °C	19:00
Max. Operating Temperature	39,6 °C	20:00
Max. Cooling Output Cooling Product (Calculated)	0 W	00:00
Max. Cooling Output Ventilation	253 W	03:00
Max. Simultaneous Cooling	253 W	03:00
Simulation Date	15/7	(Given Date)

Appendix C – Summer simulation report of Test 1 in EN 15255

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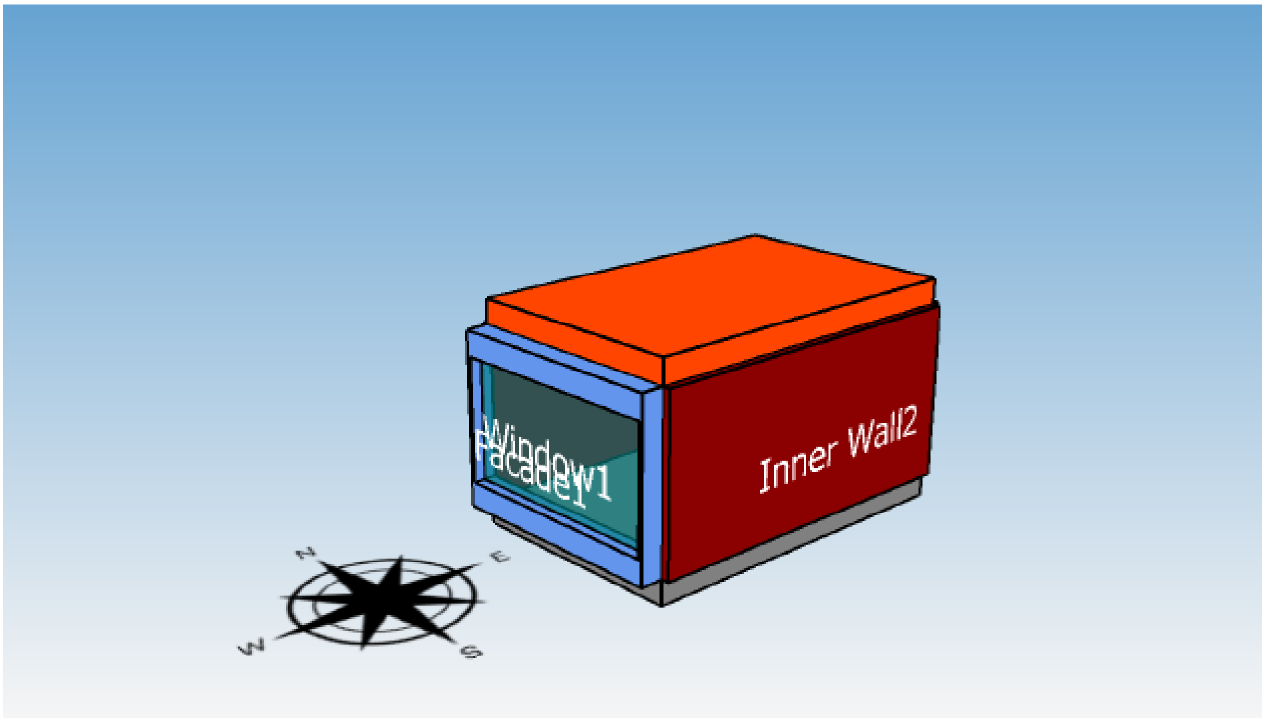
Summer Simulation:Type 1

Project Details			
Project Name	spaces	Map	Sverige
Building Name		City	EN 15255
Internal Reference		Latitude [°]	52
External Reference		Longitude [°]	0
Comments			
Created From	marwan	Date	06-May-2016



Room Elements

Type	Name	Area [m²]	Construction	U-Value [W/m² K]	Thermal Capacity [J / kg K]	Direction [°]	Roof Angle [°]	Shading Factor
Facade	Facade1	10,1	External wall Type 1	0,50	37,10	270(W)		
Window	Window1	7,0	SDP	2,21				
Inner Wall	Inner Wall1	10,1	Inner wall Type 2	0,36	2,60			
Inner Wall	Inner Wall2	15,4	Inner wall Type 2	0,36	2,60			
Inner Wall	Inner Wall4	15,4	Inner wall Type 2	0,36	2,60			
Floor	Floor1	19,8	Floor Type 4f	0,24	30,80			
Ceiling	Ceiling1	19,8	Cieling Type 4c	0,24	1,00			

1 of 3

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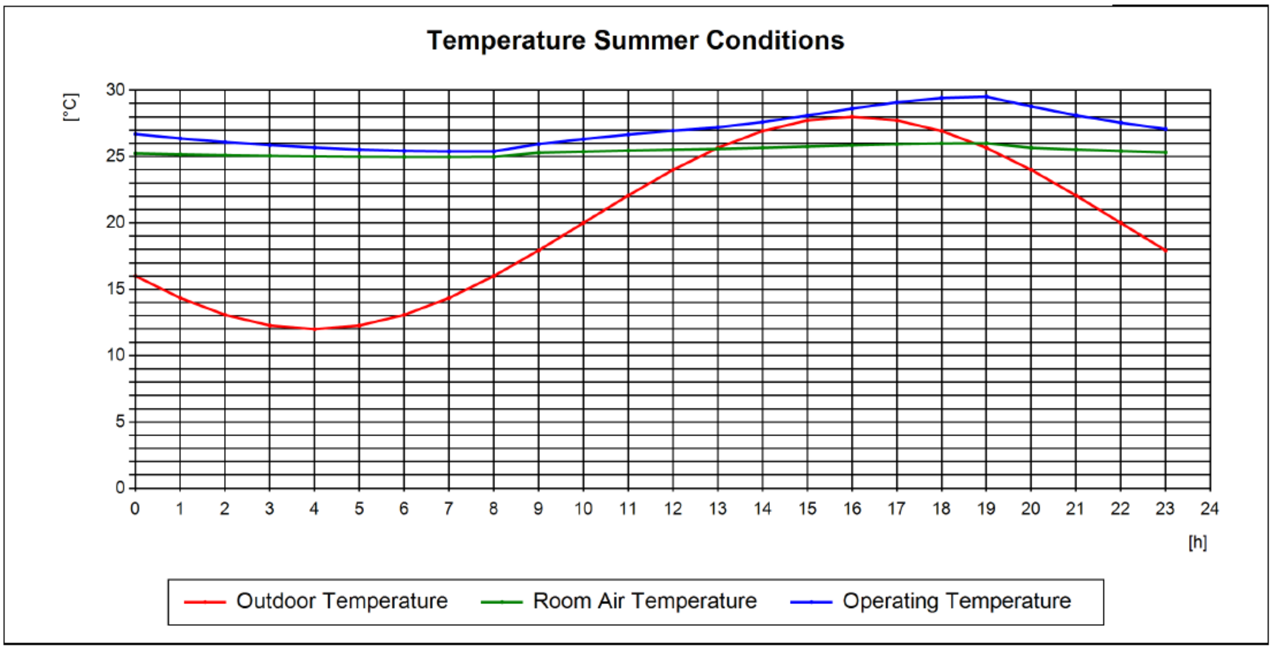

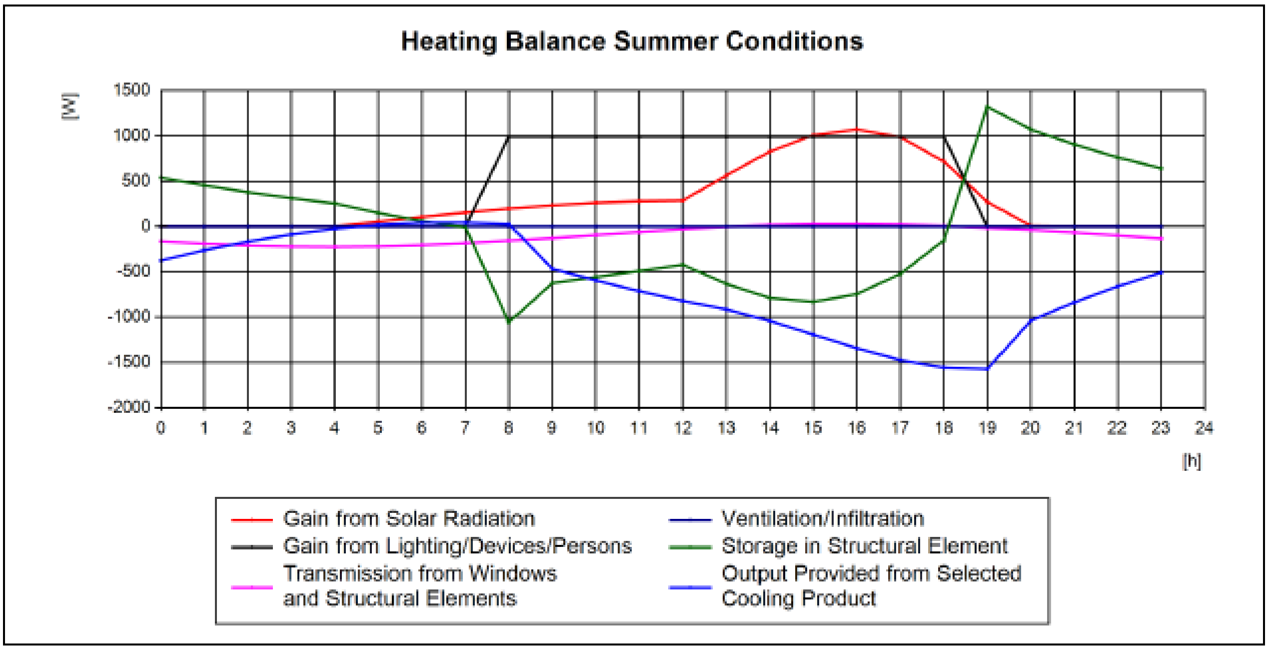

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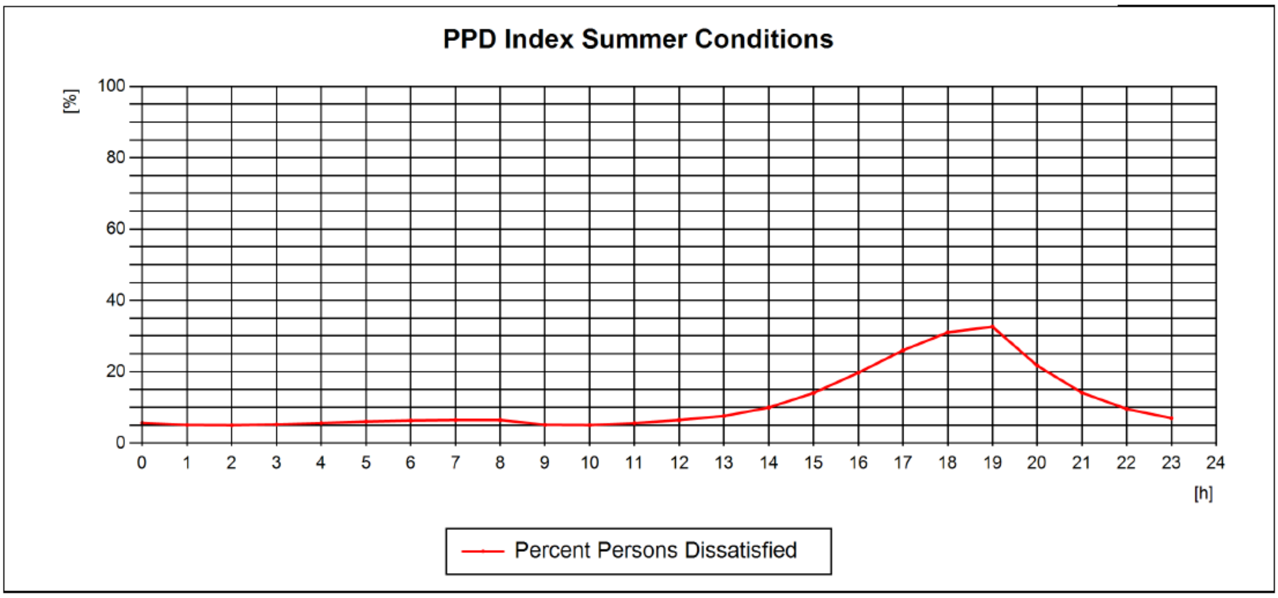

Summer Conditions		
Description	**Value**	**Time Point**
Max. Room Temperature	26,0 °C	19:00
Max. Operating Temperature	29,5 °C	19:00
Max. Cooling Output Cooling Product (Calculated)	1575 W	19:00
Max. Cooling Output Ventilation	0 W	04:00
Max. Simultaneous Cooling	1575 W	19:00
Simulation Date	15/7	(Given Date)

Simulation cooling product from the given air flow		
Product	**Air Temperature [°C] (Given)**	**Air Flow [l/s] (Calculated)**
Air Cooling (CAV System)	25,0	1223

Appendix D – Summer simulation report of Base Case in ANSI/ASHRAE 140

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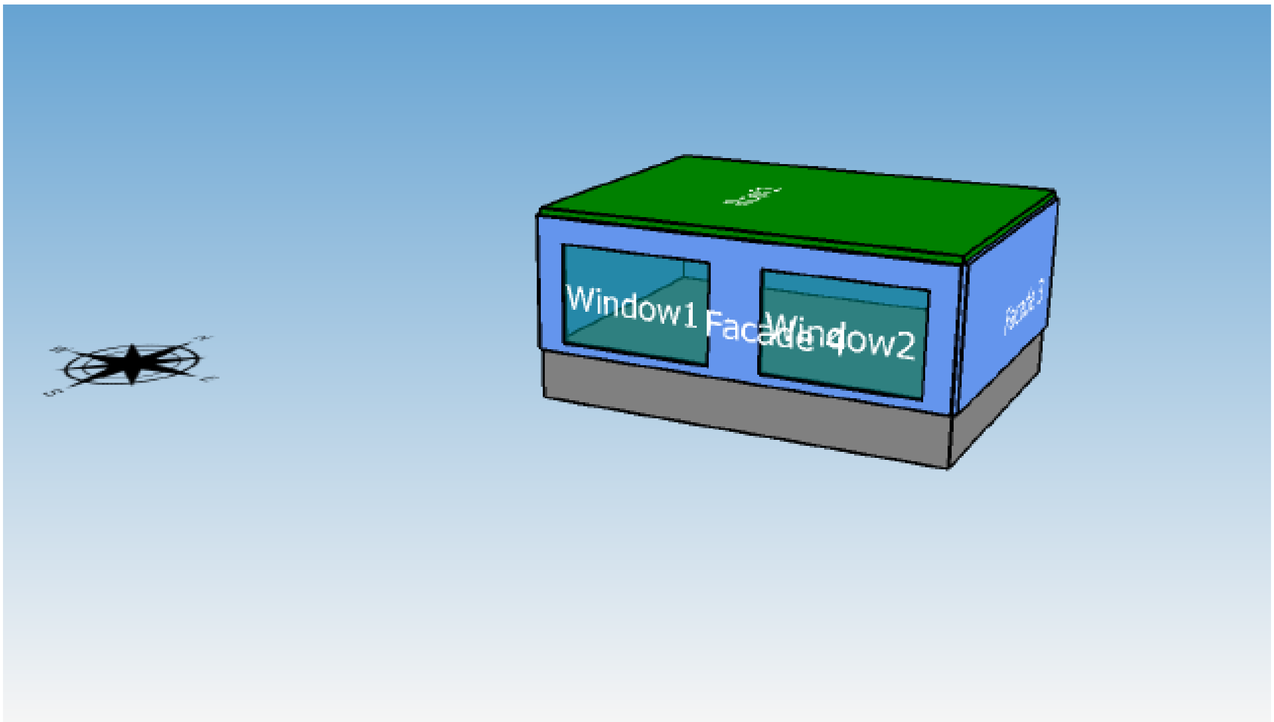
Summer Simulation:Sample room

Project Details			
Project Name	Case 600: Base case	Map	US
Building Name		City	DRYCOLD.TMY
Internal Reference		Latitude [°]	39,8
External Reference		Longitude [°]	-104,9
Comments			
Created From	marwan	Date	15-April-2016



Room Elements

Type	Name	Area [m²]	Construction	U-Value [W/m² K]	Thermal Capacity [J / kg K]	Direction [°]	Roof Angle [°]	Shading Factor
Facade	Facade 1	16,2	Lightweight base case_Wall	0,51	2,70	270(W)		
Facade	Facade 2	21,6	Lightweight base case_Wall	0,51	2,70	0(N)		
Facade	Facade 3	16,2	Lightweight base case_Wall	0,51	2,70	90(E)		
Facade	Facade 4	21,6	Lightweight base case_Wall	0,51	2,70	180(S)		
Window	Window1	6,0	Window_Case 600	3,00				
Window	Window2	6,0	Window_Case 600	3,00				
Floor	Floor1	48,0	Lightweight Case_Floor	0,07	5,40			

1 of 3

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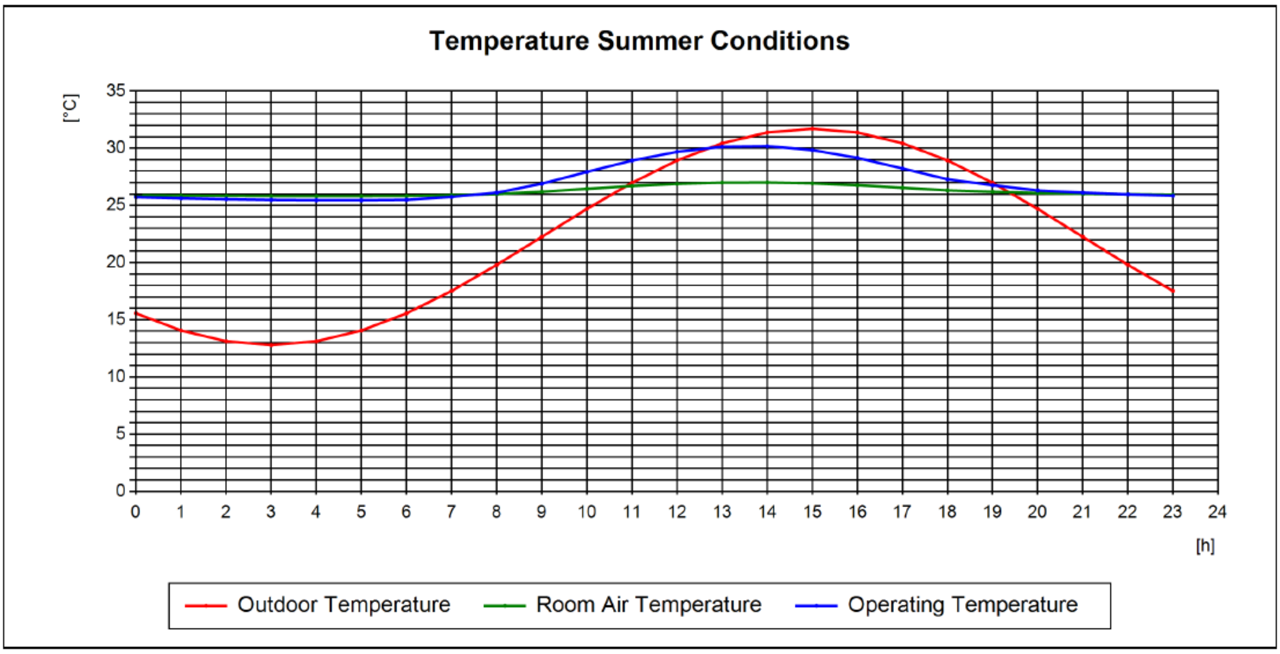
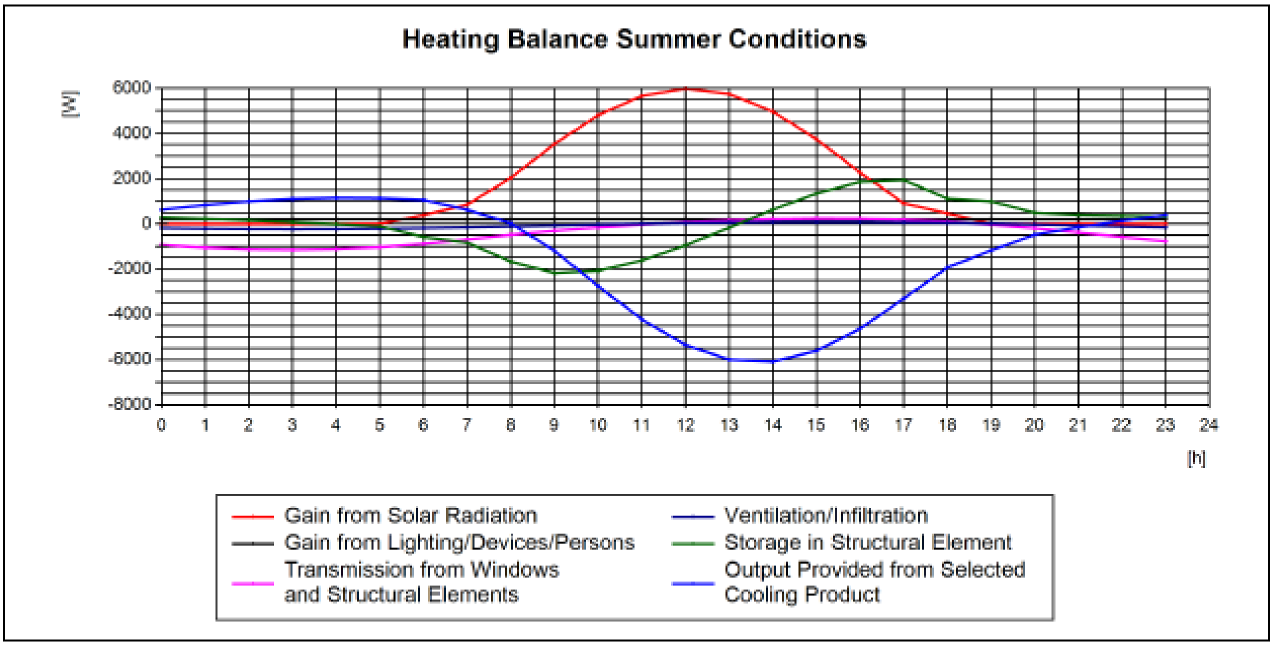
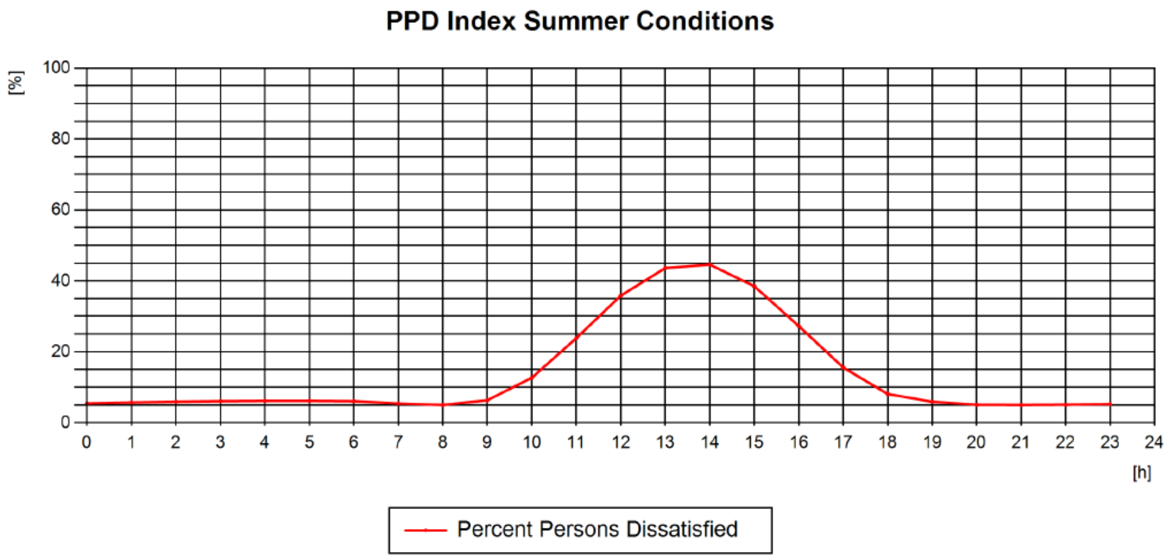
Roof	Roof1	48,0	Lightweight Case_Roof	0,31	2,20	90(E)	0,00	





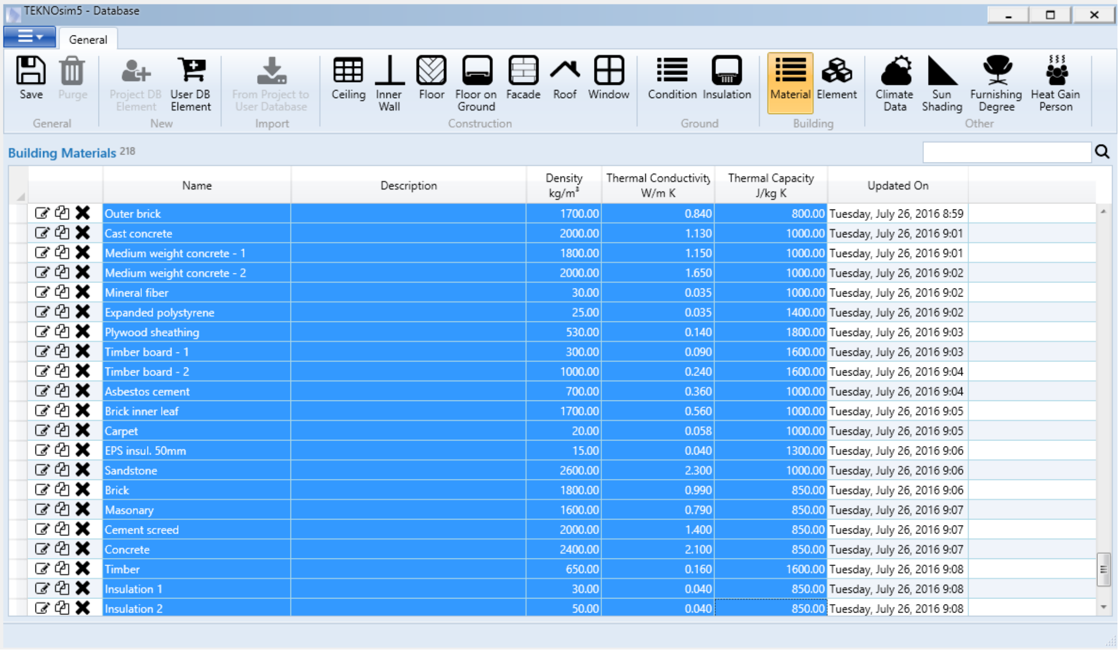


Summer Conditions		
Description	**Value**	**Time Point**
Max. Room Temperature	27,0 °C	14:00
Max. Operating Temperature	30,2 °C	14:00
Max. Cooling Output Cooling Product (Calculated)	6089 W	14:00
Max. Cooling Output Ventilation	229 W	03:00
Max. Simultaneous Cooling	6012 W	14:00
Simulation Date	15/8	(Calculated Comp. Date)

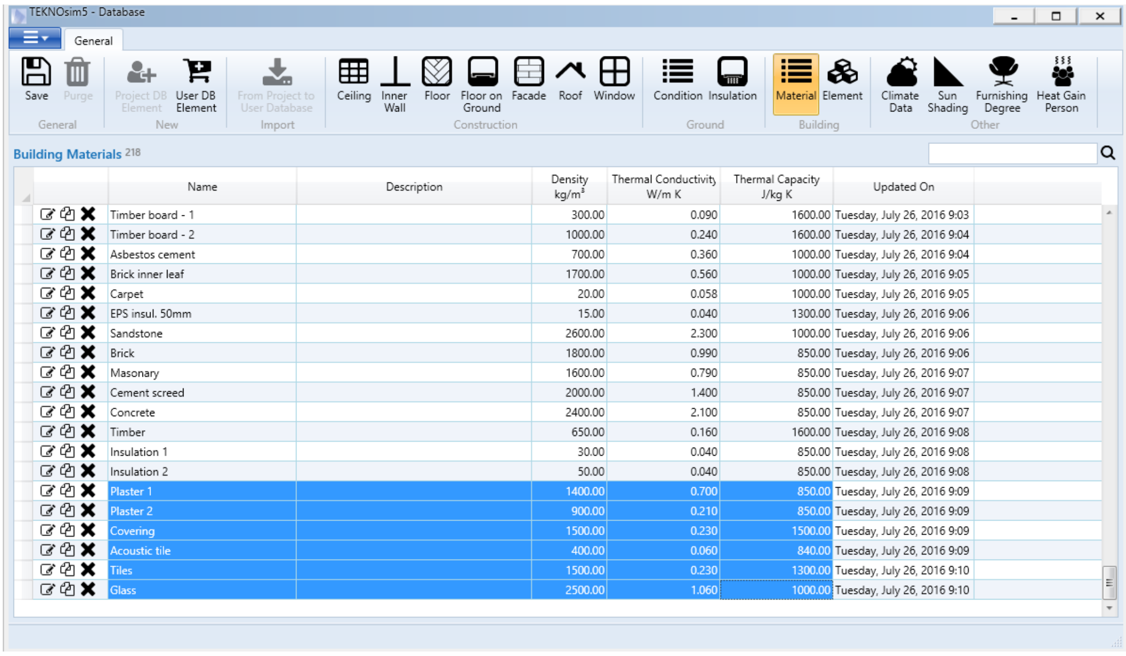
Simulation cooling product from the given air flow		
Product	**Air Temperature [°C] (Given)**	**Air Flow [l/s] (Calculated)**
Air Cooling (CAV System)	26,0	4727

Appendix E – TEKNOsim inputs for Test ases in CIBSE TM33

Material database for test G1A:

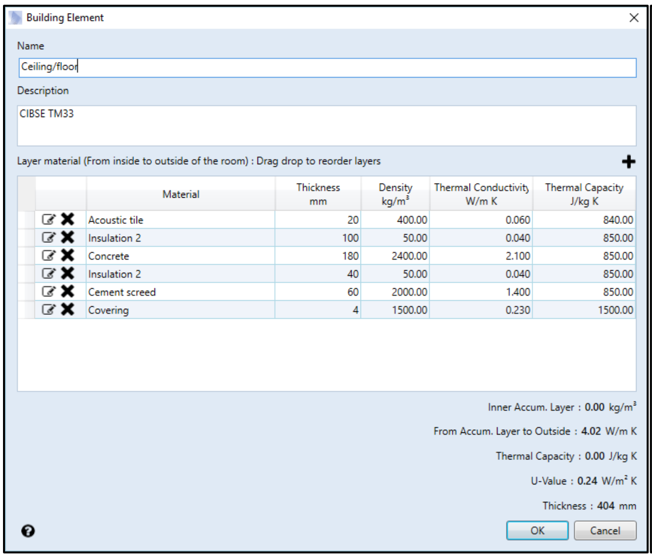


Name	Description	Density kg/m³	Thermal Conductivity W/m K	Thermal Capacity J/kg K	Updated On
Outer brick		1700.00	0.840	800.00	Tuesday, July 26, 2016 8:59
Cast concrete		2000.00	1.130	1000.00	Tuesday, July 26, 2016 9:01
Medium weight concrete - 1		1800.00	1.150	1000.00	Tuesday, July 26, 2016 9:01
Medium weight concrete - 2		2000.00	1.650	1000.00	Tuesday, July 26, 2016 9:02
Mineral fiber		30.00	0.035	1000.00	Tuesday, July 26, 2016 9:02
Expanded polystyrene		25.00	0.035	1400.00	Tuesday, July 26, 2016 9:02
Plywood sheathing		530.00	0.140	1800.00	Tuesday, July 26, 2016 9:03
Timber board - 1		300.00	0.090	1600.00	Tuesday, July 26, 2016 9:03
Timber board - 2		1000.00	0.240	1600.00	Tuesday, July 26, 2016 9:04
Asbestos cement		700.00	0.360	1000.00	Tuesday, July 26, 2016 9:04
Brick inner leaf		1700.00	0.560	1000.00	Tuesday, July 26, 2016 9:05
Carpet		20.00	0.058	1000.00	Tuesday, July 26, 2016 9:05
EPS insul. 50mm		15.00	0.040	1300.00	Tuesday, July 26, 2016 9:06
Sandstone		2600.00	2.300	1000.00	Tuesday, July 26, 2016 9:06
Brick		1800.00	0.990	850.00	Tuesday, July 26, 2016 9:06
Masonary		1600.00	0.790	850.00	Tuesday, July 26, 2016 9:07
Cement screed		2000.00	1.400	850.00	Tuesday, July 26, 2016 9:07
Concrete		2400.00	2.100	850.00	Tuesday, July 26, 2016 9:07
Timber		650.00	0.160	1600.00	Tuesday, July 26, 2016 9:08
Insulation 1		30.00	0.040	850.00	Tuesday, July 26, 2016 9:08
Insulation 2		50.00	0.040	850.00	Tuesday, July 26, 2016 9:08



Name	Description	Density kg/m³	Thermal Conductivity W/m K	Thermal Capacity J/kg K	Updated On
Timber board - 1		300.00	0.090	1600.00	Tuesday, July 26, 2016 9:03
Timber board - 2		1000.00	0.240	1600.00	Tuesday, July 26, 2016 9:04
Asbestos cement		700.00	0.360	1000.00	Tuesday, July 26, 2016 9:04
Brick inner leaf		1700.00	0.560	1000.00	Tuesday, July 26, 2016 9:05
Carpet		20.00	0.058	1000.00	Tuesday, July 26, 2016 9:05
EPS insul. 50mm		15.00	0.040	1300.00	Tuesday, July 26, 2016 9:06
Sandstone		2600.00	2.300	1000.00	Tuesday, July 26, 2016 9:06
Brick		1800.00	0.990	850.00	Tuesday, July 26, 2016 9:06
Masonary		1600.00	0.790	850.00	Tuesday, July 26, 2016 9:07
Cement screed		2000.00	1.400	850.00	Tuesday, July 26, 2016 9:07
Concrete		2400.00	2.100	850.00	Tuesday, July 26, 2016 9:07
Timber		650.00	0.160	1600.00	Tuesday, July 26, 2016 9:08
Insulation 1		30.00	0.040	850.00	Tuesday, July 26, 2016 9:08
Insulation 2		50.00	0.040	850.00	Tuesday, July 26, 2016 9:08
Plaster 1		1400.00	0.700	850.00	Tuesday, July 26, 2016 9:09
Plaster 2		900.00	0.210	850.00	Tuesday, July 26, 2016 9:09
Covering		1500.00	0.230	1500.00	Tuesday, July 26, 2016 9:09
Acoustic tile		400.00	0.060	840.00	Tuesday, July 26, 2016 9:09
Tiles		1500.00	0.230	1300.00	Tuesday, July 26, 2016 9:10
Glass		2500.00	1.060	1000.00	Tuesday, July 26, 2016 9:10

Building elements for the construction in test G3.1:


Building Element

Name: Ceiling/floor

Description: CIBSE TM33

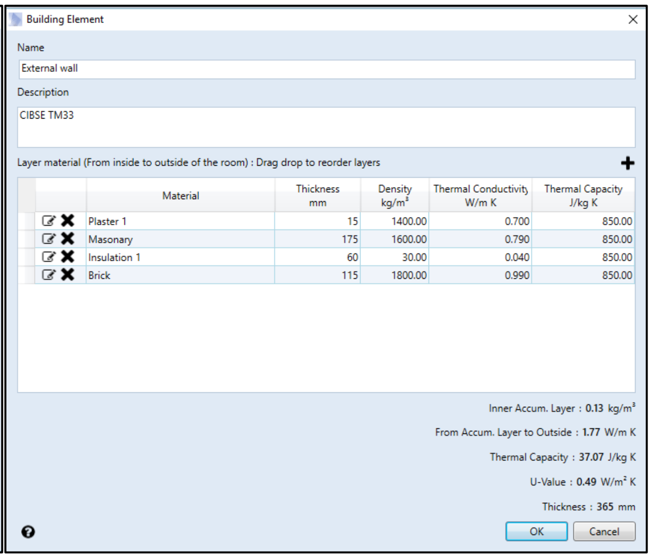
Layer material (From inside to outside of the room) : Drag drop to reorder layers

Material	Thickness mm	Density kg/m³	Thermal Conductivity W/m K	Thermal Capacity J/kg K
Acoustic tile	20	400.00	0.060	840.00
Insulation 2	100	50.00	0.040	850.00
Concrete	180	2400.00	2.100	850.00
Insulation 2	40	50.00	0.040	850.00
Cement screed	60	2000.00	1.400	850.00
Covering	4	1500.00	0.230	1500.00

Inner Accum. Layer : 0.00 kg/m²
From Accum. Layer to Outside : 4.02 W/m K
Thermal Capacity : 0.00 J/kg K
U-Value : 0.24 W/m² K
Thickness : 404 mm

OK Cancel

Ceiling and floor


Building Element

Name: External wall

Description: CIBSE TM33

Layer material (From inside to outside of the room) : Drag drop to reorder layers

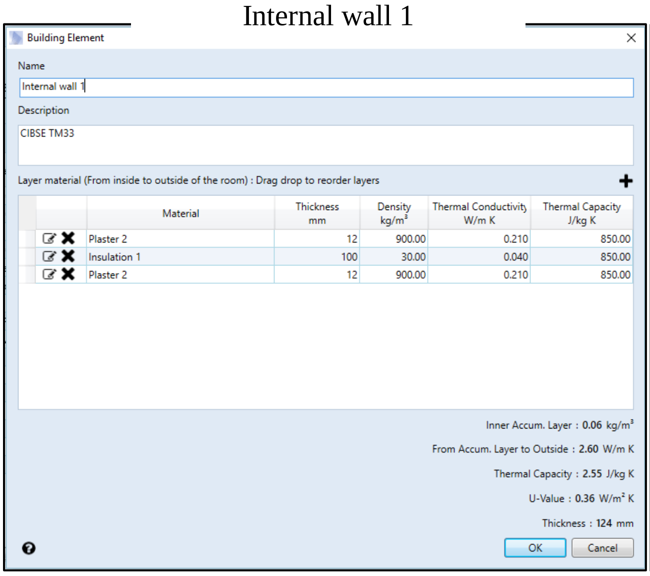
Material	Thickness mm	Density kg/m³	Thermal Conductivity W/m K	Thermal Capacity J/kg K
Plaster 1	15	1400.00	0.700	850.00
Masonary	175	1600.00	0.790	850.00
Insulation 1	60	30.00	0.040	850.00
Brick	115	1800.00	0.990	850.00

Inner Accum. Layer : 0.13 kg/m²
From Accum. Layer to Outside : 1.77 W/m K
Thermal Capacity : 37.07 J/kg K
U-Value : 0.49 W/m² K
Thickness : 365 mm

OK Cancel

External wall

Internal wall 1


Building Element

Name: Internal wall 1

Description: CIBSE TM33

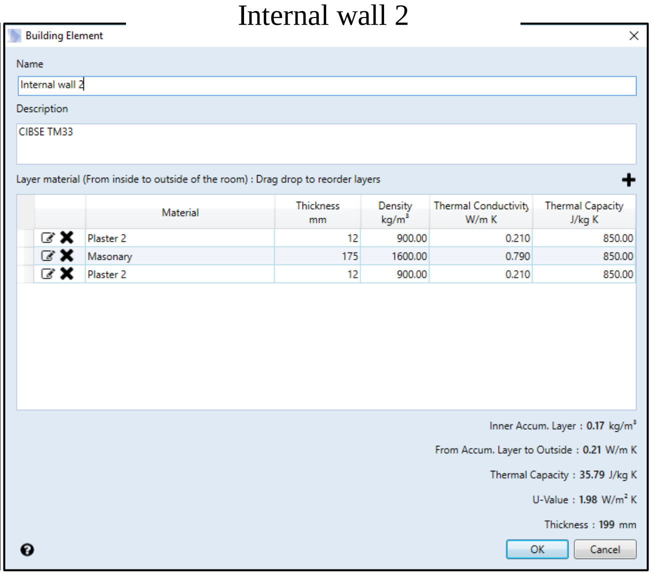
Layer material (From inside to outside of the room) : Drag drop to reorder layers

Material	Thickness mm	Density kg/m³	Thermal Conductivity W/m K	Thermal Capacity J/kg K
Plaster 2	12	900.00	0.210	850.00
Insulation 1	100	30.00	0.040	850.00
Plaster 2	12	900.00	0.210	850.00

Inner Accum. Layer : 0.06 kg/m²
From Accum. Layer to Outside : 2.60 W/m K
Thermal Capacity : 2.55 J/kg K
U-Value : 0.36 W/m² K
Thickness : 124 mm

OK Cancel

Internal wall 2


Building Element

Name: Internal wall 2

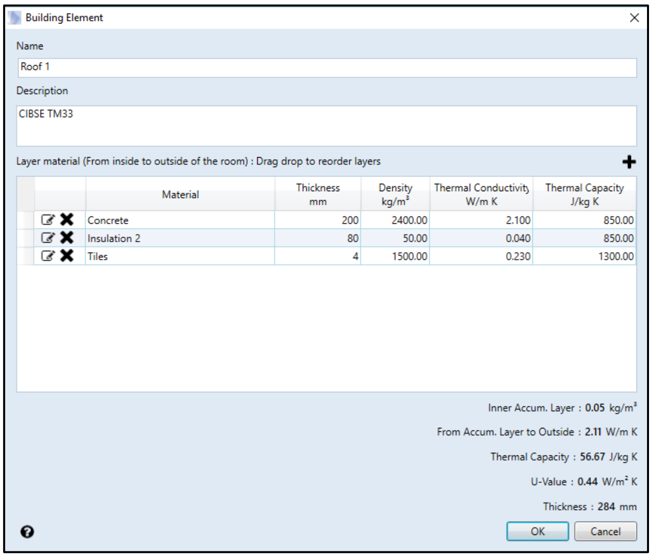
Description: CIBSE TM33

Layer material (From inside to outside of the room) : Drag drop to reorder layers

Material	Thickness mm	Density kg/m³	Thermal Conductivity W/m K	Thermal Capacity J/kg K
Plaster 2	12	900.00	0.210	850.00
Masonary	175	1600.00	0.790	850.00
Plaster 2	12	900.00	0.210	850.00

Inner Accum. Layer : 0.17 kg/m²
From Accum. Layer to Outside : 0.21 W/m K
Thermal Capacity : 35.79 J/kg K
U-Value : 1.98 W/m² K
Thickness : 199 mm

OK Cancel


Building Element

Name: Roof 1

Description: CIBSE TM33

Layer material (From inside to outside of the room) : Drag drop to reorder layers

Material	Thickness mm	Density kg/m³	Thermal Conductivity W/m K	Thermal Capacity J/kg K
Concrete	200	2400.00	2.100	850.00
Insulation 2	80	50.00	0.040	850.00
Tiles	4	1500.00	0.230	1300.00

Inner Accum. Layer : 0.05 kg/m²
From Accum. Layer to Outside : 2.11 W/m K
Thermal Capacity : 56.67 J/kg K
U-Value : 0.44 W/m² K
Thickness : 284 mm

OK Cancel

Roof

LUND UNIVERSITY

Dept of Architecture and Built Environment: Division of Energy and Building Design
Dept of Building and Environmental Technology: Divisions of Building Physics and Building Services