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FACULTY OF MECHANICAL ENGINEERING
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HEATING ENERGY NEED IN LARGE SPACE BUILDINGS

DIPLOMA THESIS

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ABSTRACT

The calculation of annual heating energy consumption for large space buildings must be performed taking special consideration due to the building height. This thesis explores the possible calculation standards which may be followed in order to obtain an estimate of this value. A Case Study building was selected and an estimate of its net annual heating energy consumption was calculated by using the methods in the EN 13790 and CIBSE TM41 standards. These results were used as inputs for the calculation on EN 15316-2-1, which result is the total consumption, taking into account losses of the heating emission system and special considerations for radiant heating and large space buildings. The results obtained by means of each main method have a percentage difference of 38 %. By analyzing the calculations, it was concluded that the calculation methods are influenced differently by the building inertia and effects if intermittent heating. By performing a theoretical comparison, it was determined that the calculations are more similar for buildings of heavier classes (15% percentage difference for “very heavy” class building considered). The total energy consumption results are also different due to their direct dependence on the net values obtained via EN 13790 and CIBSE TM41.

DECLARATION

I declare that this diploma thesis entitled "Heating Energy Need in Large Space Buildings" is my own work performed under the supervision of Ing. Ondřej Hojer, Ph.D., with the use of the literature presented at the end of my diploma thesis in the list of references.

In Prague 15.07.2016 Natasha Carolina Rojas Aparicio

signature

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LIST OF SYMBOLS AND ABBREVIATIONS

- EPB: energy performance of buildings.
- CEN : Comité Européen de Normalisation (French: European Committee for Standardization).
- TC : Technical committee.
- HVAC : Heating, ventilation and air conditioning.
- H : heat transfer coefficient
- θ : temperature
- θ_e : external temperature
- θ_i : internal temperature
- θ_o : overnight temperature
- θ_{So} : switch-on temperature
- θ_b : base temperature
- t : time
- Q_p : heating system output (at full load)
- Q_{ls} : heat losses by transmission and ventilation
- Φ_{int} : heat dissipated by appliances
- Q_{int} : internal heat gains
- H_{sol} : average monthly solar irradiance
- Φ_{sol} : heat flow from solar sources
- Q_{sol} : solar heat gains
- Q_{gn} : heat gains from solar and internal sources
- η_{gn} : gain utilization factor
- $\alpha_{red,H}$: dimensionless reduction factor for intermittent heating
- Q_H : energy need for heating
- D_m : monthly degree-days
- τ : building time constant
- τ_{Ho} : reference building time constant
- a_H : dimensionless numerical parameter related to τ
- a_{Ho} : dimensionless numerical parameter related to τ

- $b_{red,H}$: fraction of heating period
- $a_{red,H}$: is the dimensionless reduction factor for intermittent heating
- Y_H : dimensionless heat balance ratio for the heating mode
- $Q_{l,em}$: additional heat loss of the heat emission
- f_{rad} : factor for radiation effect
- f_{int} : factor for intermittent operation
- f_{hyd} : factor for hydraulic equilibrium
- $\eta_{l,em}$: total efficiency level for the heat emission
- η_{syst} : total efficiency level for the system
- f_H : fraction of heating period

INTRODUCTION

When designing a new building, it is vital to consider its thermal properties and to determine an estimate of the energy consumption of HVAC systems; this allows for the possibility of design changes which may lead to savings in energy costs. It is also very important to have a tool that allows the calculation of the energy consumption for HVAC systems in existing buildings. This estimate may be used to compare with actual consumption and verify the system operation is as designed.

There are various tools that allow the calculation of annual heating energy consumption for residential and non-residential buildings. However, large space buildings have specific characteristics that must be taken into consideration to obtain accurate results.

For this thesis, two main calculation procedures were followed in order to calculate the annual heating energy consumption of a Case Study building. These results were then used as input to determine the extra consumption due to factors such as non-uniform temperature distribution (caused by heights > 4 m) and efficiency and auxiliary energy of the heat emission system.

The Case Study building is an existing building located in Roudnice nad Labem, Czech Republic. Using the characteristics of this building, as well as the weather conditions for the location, the calculation of the net annual heating energy was performed using calculation methods presented in two European standards; EN 13790 and CIBSE TM41. Based on the results of these calculations, the calculations proposed in EN 15316-2-1 were performed in order to obtain the total heating energy consumption.

Goals

- To perform critical review of available methods used for evaluation of heat consumption of large space buildings.
- To investigate the cause of the discrepancies between the calculations of annual energy consumption for heating large spaces when using different standards.

Objectives

- Determine geometrical and thermal conditions for a selected case study building to be used as inputs as well as the weather conditions for the location.
- Calculate the annual heat consumption using the following standards:
    - EN 13790
    - CIBSE TM41:2006
- Calculate the extra heating energy consumption using:
    - EN 15316-2-1 (formerly DIN V 18599-5)
- Review the differences between the calculation procedures used in the standards.

Structure of the thesis

The first part of this thesis work is intended to define basic concepts necessary to carry out the calculations. Later, a description of the Case Study building and the inputs that will be used for all calculations are presented. Then the calculations procedures for each standard are briefly explained followed by the relevant results and analyses of these results. Finally, the conclusions that were reached by the development of the thesis are listed.

CHAPTER 1

THEORETICAL BASIS

All the relevant concepts for the development of this research are discussed in the current chapter. Main definitions and their relevant interpretation for this thesis work are introduced first, including heat consumption, large space buildings, heating season and heat gains. Later, the three standards for calculation used throughout the thesis are described in a broad sense; EN 13790, CIBSE TM41 and EN 15316-2-1. For each standard, the main inputs and outputs are listed and other relevant definitions introduced.

1.1 Annual heat consumption

For the purpose of this document, the annual heat consumption may be described as the annual energy needs required for maintaining a specified set-point temperature in a building during the heating season, including auxiliary energy for heating and ventilation as well as losses of the heating system.

The definition found in EN 13790: “A sum of energy needs for heating, heating system losses and auxiliary energy of the heating system, per energy carrier is, expressed in MJ. The losses and auxiliary energy comprise generation, transport, control, distribution, storage and emission.” [1]

The definition found in CIBSE TM41: “The heat demand of a building comprises fabric transmission losses, air exfiltration losses and mechanical ventilation loads. (This publication does not consider hot water and other process loads).” [2]

1.2 Large indoor space buildings

For heating and ventilation purposes, a large space is considered a building or room with a height above 4 m. [3]

1.3 Heating season

"Period of the year during which a significant amount of energy for heating or cooling is needed" [1]. The length of the heating season may be determined differently according to the standard being used as reference.

1.4 Internal heat gains

The internal heat gains considered for the calculations in this thesis include:

- metabolic heat from occupants and dissipated heat from appliances;
- dissipated heat from lighting devices;
- heat dissipated from or absorbed by hot and mains water and sewage systems;
- heat dissipated from or absorbed by heating, cooling and ventilation systems;
- heat from or to processes and goods.

1.5 Calculation methods

There are several methods via which the energy consumption for heating a building may be calculated. For the purpose of this thesis work two main calculation procedures were followed, these methods are presented in the following standards:

- EN 13790: Energy performance of buildings – Calculation of energy use for space heating and cooling;
- CIBSE TM41 Degree-days: Theory and Application.

In addition, a supplementary standard was reviewed and used. This standard deals with the efficiency of heating emission systems and provides a method to determine the corresponding additional heat losses (which are part of the total heating energy consumption).

- EN 15316-2-1: Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 2-1: Space heating emission systems.

1.6 Description of EN 13790: Energy performance of buildings – Calculation of energy use for space heating and cooling.

"The standard provides a calculation method for the design and evaluation of thermal and energy performance of buildings. It presents a coherent set of calculation methods at different levels of detail, for the energy use for the space heating and cooling of a building and the influence of the heating and cooling system losses, heat recovery and the utilization of renewable energy sources."[1]

1.6.1 Main inputs

The main inputs needed to use EN 13790 are:

- transmission and ventilation properties;
- heat gains from internal heat sources, solar properties;
- climate data;
- description of building and building components, systems and use;
- comfort requirements (set-point temperatures and ventilation rates);
- data related to the heating, cooling, hot water, ventilation and lighting systems:
  - partition of building into different zones for the calculation (different systems may require different zones);
  - energy losses dissipated or recovered in the building (internal heat gains, recovery of ventilation heat loss);
  - air flow rate and temperature of ventilation supply air (if centrally pre-heated or pre-cooled) and associated energy use for air circulation and pre-heating or pre-cooling;
  - controls. [1]

1.6.2 Main outputs

The main outputs that may be obtained from the calculation using EN 13790 are:

- annual energy needs for space heating and cooling;
- annual energy use for space heating and cooling;

- length of heating and cooling season (for system running hours);
- auxiliary energy use for heating, cooling and ventilation systems. [1]

1.6.3 Calculation procedure – Annual heat consumption

- Choose the type of calculation method (time discretization).
- Define the boundaries of the total of conditioned spaces and the unconditioned spaces.
- If required, define the boundaries of the different calculation zones.
- Define the indoor conditions for the calculations and the external climatic and other environmental data inputs.
- Calculate, per time period and building zone, the energy need for heating.
- Combine the results for different periods and different zones serviced by the same systems and calculate the energy use for heating taking into account the dissipated heat of the heating systems. Combine the results for different building zones with different systems.
- Calculate the operational length of the heating and season.
- Depending on the application and type of building, it may be required to perform the calculation of the energy need for heating and cooling in multiple steps, for instance to account for interactions between the building and the system, or between adjacent zones.

1.6.4 Methods

This standard offers two types of method: a dynamic method and a quasi-steady state method. Included in those categories, the standard may also be used to perform a monthly calculation, a simple hourly calculation or a dynamic hourly calculation. This thesis will focus on a monthly, quasi steady-state method. The quasi steady-state method calculates a heat balance over a month; therefore it is possible to ignore instantaneously stored or released heat. However, the accumulation is taken into account by an empirically calculated gain utilization factor.

1.6.5 Gain utilization factor

Some of the heat gains are not used by the building, the product of the gain utilization factor and the heat gains results in the amount of heat which will actually be utilized put of the total amount of heat gains.

1.7 Description of CIBSE TM41 Degree-days: Theory and Application.

The publication is a standard for Great Britain; it provides a definition and methods for calculating degree-days and guidance on their use. It may be used to determine the thermal performance of particular designs by designers and also for the assessment of energy performance for existing buildings.

The publication includes theory about degree-days and the mathematical calculation required to obtain them. More importantly, it presents detailed mathematical applications of degree-days to building energy estimation, including the effects of intermittent plant operation. The calculations provide simplification and cannot replace full thermal simulations, but can be used as a simple a fast approach to calculate typical magnitudes of consumption.

1.7.1 Main inputs

The following input data is required to complete the calculations described in CIBSE TM41. The general requirements are described and the specific data used for the purpose of this thesis is mentioned in parentheses.

- Climate data (hourly ambient temperatures).
- Description of building and thermal properties.
- Ventilation demands.
- Heat gains from internal sources and solar properties (or solar heat gains)
- Schedule for intermittent operation.
- Building set-point internal temperature.

1.7.2 Main outputs

The main outputs that may be obtained from following the calculations described in CIBSE TM41 are:

- monthly base temperature for heating or cooling operation;
- switch-on times for heating or cooling system control;
- degree-hours and degree days;
- annual energy demand for space heating and cooling.

1.7.3 Degree-days

"Degree-days are essentially the summation of temperature differences over time, and hence they capture both extremity and duration of outdoor temperatures. The temperature difference is between a reference temperature and the outdoor air temperature. The reference temperature is known as the base temperature which, for buildings, is a balance point temperature, i.e. the outdoor temperature at which the heating (or cooling) systems do not need to run in order to maintain comfort conditions." [2]

Degree-days may be calculated using different approaches and therefore different input data.

- Mean degree-hours; calculated from the hourly temperature record.
- Using daily maximum and minimum temperatures; e.g. the Meteorological Office equations [2].
- From mean daily temperatures.
- Direct calculation of monthly degree-days from mean monthly temperature and the monthly standard deviation; e.g. Hitchin's formula [2].

1.7.4 Base temperature

In a heated building during cold weather heat is lost to the external environment. Some of this heat is replaced by casual heat gains to the space - from people, lights, machines and solar gains - while the rest is supplied by the heating system. Since the casual gains provide a contribution to the heating within the building, there will be some outdoor temperature, below the occupied set point temperature, at which the heating system will not need to run. At this point the casual gains equal the heat loss. This temperature will be the base temperature for the building.[2]

1.7.5 Calculation procedure – Annual heat consumption

- Calculate the building time constant.
- Calculate the optimum heating system switch-on temperature.
- Calculate the mean 24-hour internal temperature.
- Calculate the base temperature.

- Calculate monthly degree days.
- Calculate the monthly heat demand.
- Calculate the uncertainty in the estimate.

1.8 Description of EN 15316-2-1: Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 2-1: Space heating emission systems.

This standard is part of a package of EPB standards that deal with energy performance calculation and other related aspects. EN 15316-2-1 provides the specific part related to the space heating emission system's losses and its additional energy requirements which must be included in the annual heat consumption calculation for the building.

The calculation method is used for the following applications:

- calculation of the additional energy losses in the heat emission system;
- optimization of the energy performance of a planned heat emission system, by applying the method to several possible options;
- assessing the effect of possible energy conservation measures on an existing heat emission system, by calculation of the energy requirements with and without the energy conservation measure implemented.

1.8.1 Main inputs

In order to calculate the heat losses of the heat emission and control systems using EN 15316-2-1, the following input information is required;

- the building energy need for space heating (building thermal properties and the indoor and outdoor climate);
- non-uniform internal temperature distribution in each thermal zone (stratification, emitters along outside wall / window, differences between air temperature and mean radiant temperature);
- emitters embedded in the building structure towards the outside or unheated spaces;
- control of the operative temperature (local, central, set-back , thermal mass, etc);
- auxiliary consumption.

The building energy need for heating is an input for EN 15316-2-1, and it is indicated that it should be obtained from the calculation procedure presented in EN 13790.

1.8.2 Main outputs

The possible results of following the calculation methods described in EN 15316-2-1 are:

- total emission system heat losses;
- auxiliary energy consumption;
- recoverable heat losses.

1.8.3 Calculation procedure

The system losses are calculated separately for thermal energy and electrical energy, in order to determine the final energy. The main part of the calculation is that of the losses in the heat emission systems, there are two proposed methods by which this may be done using EN 15316-2-1.

The first method uses efficiencies of the system, taking into account the effects of temperature distribution (depending on room height), the accuracy of the control system and the efficiency of embedded systems [3].

The second method corrects the heat consumption by using an equivalent increase in internal temperature. The internal temperature is increased by:

- the spatial variation due to the stratification, depending on the emitter;
- the temporal variation depending on the capacity of the control device to assure a homogeneous and constant temperature.

CHAPTER 2

INPUTS / CASE STUDY

The same inputs must be used for all calculations in order to obtain a sensible overview and comparison between results using different calculation methods. A case study building was selected and the inputs for that building are presented in this chapter. It includes general description of the building including use, location, dimensions and systems as well as the weather inputs considered (relevant temperature and solar irradiation data). Finally, the overall building heat load is presented.

2.1 Case study description

The selected case study consists of an industrial building with an approximate floor area of 2500 m^2. The building is located in Roudnice nad Labem, Czech Republic, a satellite view is presented in Figure 2.1. It is used as a manufacturing, assembly and welding facility.

Figure 2.1 Satellite image of the Case Study building

2.1.1 Distribution of the space

The building consists in a large rectangular structure with a height of 7.2 m^2. On the west wall there is an adjacent building which is considered to have the same internal temperature, the remaining walls are exposed to ambient temperatures. There is a main space which accounts for the majority of the floor area; in addition, there are separate spaces for welding, offices (including restrooms and cleaning room) and a room for the ventilation and heat recovery equipment. Figure 2.2 shows the layout of the structure and the distribution of the space. The main space, welding area and ventilation rooms don't have windows. The only three windows are east facing, in the office area, there is one door to the exterior also in the office area. There are two gates which are considered glazed elements on the east façade, one on each side of the office area. There are four long skylights on the ceiling. The dimensions for the relevant element groups of the building are shown in Table 2.1.

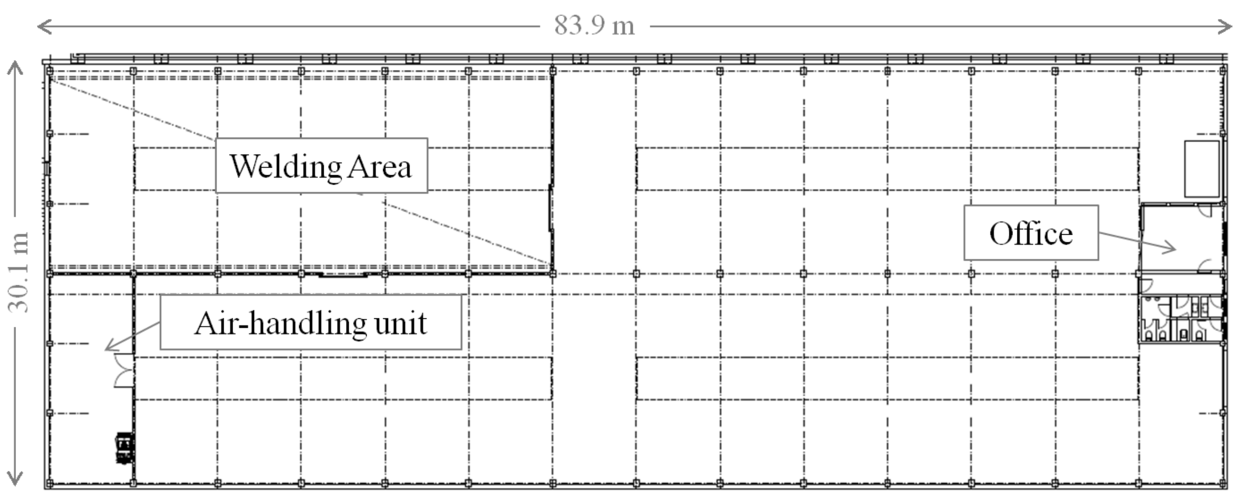

Figure 2.2 Building Layout

Table 2.1 Relevant building dimensions

Internal volume	18656	$\mathbf{m^3}$
Floor area	2528	$\mathbf{m^2}$
External walls + ceiling	3566	$\mathbf{m^2}$
Adjacent walls	604	$\mathbf{m^2}$
Glazed elements	431	$\mathbf{m^2}$
Doors	3.60	$\mathbf{m^2}$

The general dimensions of the building walls and opening, as well as their respective U-values, which were taken as inputs for all calculations, are displayed in Table 2.2. The orientation of the element is represented by the letter preceding it, i.e. S : south facing.

Table 2.2 Dimensions and heat transfer coefficients of walls and openings.

Element	Qty.	Length	Width or height	Element area	U-value
-	-	m	m	m^2	$W.m^{-1}.K^{-1}$
S - Wall	1	83.9	2.4	201.36	0.38
S - Wall	1	83.9	4.8	268.06	0.28
S - Element	41	0.95	1.75	68.16	1.8
S - Element	40	0.95	1.75	66.50	1.8
Ceiling	1	83.9	30.1	2131.19	0.24
W – Skylight*	2	35.85	3	215.10	1.8
E – Skylight*	2	29.85	3	179.10	1.8
N - Wall	1	83.9	7.2	604.08	0.38
W - Wall	1	30.1	2.4	72.24	0.38
W - Wall	1	30.1	4.8	142.68	0.28
W - Door	1	0.9	2	1.80	1.8
E - Wall	1	30.1	2.4	72.24	0.38
E - Wall	1	30.1	4.8	106.18	0.28
E - Window	1	1.2	1.2	1.44	1.2
E - Window	2	1.2	0.6	1.44	1.2
E - Gate	2	4.1	4.1	33.62	1.2
E - Door	1	0.9	2	1.80	1.8
Floor	1	83.9	30.1	2525.39	0.8

*** E = on the eastern side of the ceiling, W = on the western side of the ceiling.**

2.1.2 Thermal properties of elements

Table 2.3 displays the materials and respective thermal properties of the building elements used in the calculations.

Table 2.3 Properties of the construction materials

Element	Material	Area	Density	Specific heat
-	**-**	**m^2**	**kg/m^3**	**J/(kg.K)**
Floor	Concrete	2525	2400	1000
Ceiling	Cladding	2525	160	840
External walls	Light concrete blocks	1207	1750	960
Internal partitions	Light concrete blocks	342	1750	960
Internal partitions	Plasterboard	108	881	1000
Glazed elements	Glass	431	2500	840

2.1.3 Glazed elements

The main walls of the building contain few glazed elements; there are only windows in the office area and two gates on the east façade. The main glazed area is contained in the four skylights located on the ceiling. Table 2.4 displays the dimensions and orientations of the building's glazed elements.

Table 2.4 Properties of glazed elements

Element	Qty.	Dim 1	Dim 2	Area	Orientation	Slope
-	**-**	**m**	**m**	**m^2**	**-**	**Deg**
WC window	2	1.2	0.6	1.44	East	90°
Office window	1	1.2	1.2	1.44	East	90°
Gate	2	4.1	4.1	33.62	East	90°
Western Skylight	2	35.85	3	215.1	-	0°
Eastern Skylight	2	29.85	3	179.1	-	0°

2.1.4 Heating and ventilation systems

The building is heated by radiant strips placed on each side of the skylights. Isothermal ventilation is used for the entire building, with 0.4 air changes per hour for the main space, offices and ventilation room, and 6 air changes per hour for the welding room. There are ventilation losses due to infiltration (0.4 air changes per hour) for the entire building.

Heat losses due to infiltration of cold air into the space are considered by including a rate of 0.5 air changes per hour.

2.1.5 Schedule

The building occupants work during two 8-hour shifts (16 hours per day), every day of the year. The heating system must be controlled in a way that the set point temperature is reached at the beginning of the work day.

2.2 Weather data

The weather data used for the calculations is for Prague, Czech Republic due to the difficulty of acquiring data for Roudnice nad Labem. It was considered appropriate to use the climate data for Prague taking into account that the distance between both cities is 50 km, and the weather conditions are very similar.

2.2.1 Temperatures

For the calculation proposed by EN 13790, mean monthly temperatures for Prague were used; they are shown in Table 2.5. The monthly temperatures were obtained by averaging hourly weather data from the Energy Plus weather database.

Table 2.5 Mean monthly temperatures for Prague in degrees Celsius

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-1.50	-2.07	3.55	7.94	13.01	15.63	17.32	17.62	13.33	8.38	2.23	0.83

For the calculation of degree-days using CIBSE TM41, hourly weather data was used. The weather file includes a Test Reference Year in Prague and it was obtained from the Energy Plus weather database.

2.2.2 Solar irradiation

Monthly solar irradiation data for Prague was reviewed taking into account the building characteristics. The only glazed elements are located on the east façade with a slope of 90°, additionally; there are skylights on the ceiling with a 0° slope. Therefore, irradiation data for the aforementioned conditions was obtained. The data used [4] is presented in Table 2.6.

Table 2.6 Solar irradiation for Prague in kW.h.m^{-2}

β / Orien.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0°	20,8	37,0	72,2	113,8	148,8	146,2	144,3	136,2	87,1	56,5	25,2	14,9
90° / E	14,1	25,5	46,9	74,2	87,0	90,0	84,1	80,4	53,3	38,7	18,0	11,2

2.3 Internal heat sources

For the calculation of internal heat gains, the following considerations were taken into account according to EN 13790.

- Minor amounts of heat dissipated in the hot water system, the space heating system and ventilation system that are actually recovered in the building may be ignored in the calculation of the building energy need for heating and/or cooling and, instead, be dealt with in the calculation of the performance of the system by adequate adjustment factors.[1] i.e. considered in EN 15316-2-1.
- It can be assumed that the heat dissipated by processes and goods is minor and may be neglected for the purpose of these calculations.

2.3.1 Heat dissipated by occupants, appliances and lighting devices

The data for heat dissipation from occupants and appliances was obtained from EN 13790 Annex I. The heat dissipated by lighting devices was obtained from EN 15193-1 Annex F and is displayed in Table 2.7.

Table 2.7 Heat dissipated from internal sources in W.m^{-2}

Type	Criteria	Selection	Heat diss. [W.m^{-2}]
Occupants	Class of occupation density	V	2
Appliances	Building use	Assembly	1
Lighting	Building use	Manufacture	5

2.4 Building heat load

The heat load from the building was determined following the method described in EN 12831 [5], taking into account transmission and ventilation heat losses. The relevant parameters for this calculation, as well as the resulting heat load, are presented in Table 2.8.

Table 2.8 Building heat load

θ_{sp}	C	18
$\theta_{e,design}$	C	-12
$H_{T,ext\ walls}$	W/K	1968
$H_{T,ground}$	W/K	219
$H_{Ventilation}$	W/K	3140
$Q_{p,tr,ext.walls}$	W	59040
$Q_{p,tr,ground}$	W	6570
$Q_{p,Ventilation}$	W	94200
$Q_{p,total}$	W	**159810**

CHAPTER 3

CALCULATION OF HEATING ENERGY CONSUMPTION ACCORDING TO EN 13790

This chapter describes the calculation procedure carried out in order to obtain the annual heat consumption following the monthly method presented in EN 13790. There is a brief explanation for of the selection of the method first. The calculation of heat losses by transmission and ventilation is described as well as the calculation of solar and internal heat gains. Finally the parameters used for the annual balance are presented. All sections include tables which display the relevant monthly values.

3.1 Monthly method

Out of the methods proposed in EN 13790, the monthly method was selected as a simple approach to obtain the annual heat consumption. Dynamic / hourly methods were not selected because they are more time consuming methods which give accurate results when it is necessary to study the behavior of the building energy balance at given times or time periods. “The monthly calculation gives correct results on an annual basis, but the results for individual months close to the beginning and the end of the heating and cooling season can have large relative errors.” [1]

All the components of the energy balance were calculated for each month, using the average monthly weather data. The monthly gain utilization factor is determined in order to estimate the required heating energy per month and finally the summation for the twelve months produces the value of heat consumption for the year.

3.2 Heat losses

The procedure specified in the standard to calculate heat losses by transmission and ventilation is similar; it is necessary to determine the transmission heat transfer coefficients for each element and the ventilation heat transfer coefficient, then the heat transfer is the summation of the product of: the coefficients, the temperature difference and the duration of the period (month).

3.2.1 Determination of the heat transfer coefficient

An equivalent transmission heat transfer coefficient **H** was calculated to determine the heat transfer through the walls, glazed elements, floor and ceiling of the building. The elements' U-values were known and an equivalent U-value according to EN 12831 [6] was determined for the case of a floor slab on ground level.

A ventilation heat transfer coefficient was also determined taking into account an infiltration rate of 0.3 air changes per hour. Table 3.1 presents the heat transfer coefficients for the relevant element groups.

Table 3.1 Heat transfer coefficients in $W.K^{-1}$

Type	H [$W.K^{-1}$]
External elements	1968.02
Floor	219.48
Ventilation	3140.48
Total	**5327.98**

The resulting heat transfer $\mathbf{Q_{ls}}$ by transmission and ventilation is presented in Table 3.2 on a monthly basis.

Table 3.2 Monthly and annual heat loss by transmission and ventilation

Month	θ_e	days	t	Q_{ls}	Q_{ls}
-	C	-	h	MJ	kW.h
January	-1.50	31	744	278228	77286
February	-2.07	28	672	258633	71843
March	3.55	31	744	206258	57294
April	7.94	30	720	138976	38604
May	13.01	31	744	71157	19766
June	15.63	30	720	32765	9101
July	17.32	31	744	9750	2708
August	17.62	31	744	5363	1490
September	13.33	30	720	64530	17925
October	8.38	31	744	137301	38139
November	2.23	30	720	217845	60513
December	0.83	31	744	244996	68054
Total				**1665801**	**462722**

3.3 Heat gains

The heat gains are determined in a simplified manner. The calculation of internal heat gains is simplified by taking into account only the most relevant internal heat sources (as detailed in section 2.3). The calculation of solar heat gains is simplified by assuming that the solar heat gains through opaque elements is "only a small portion of the total solar heat gains and are partially compensated by radiation losses from the building to clear skies." [1] Figure 3.1 presents a summary of monthly heat gains from solar and internal sources.

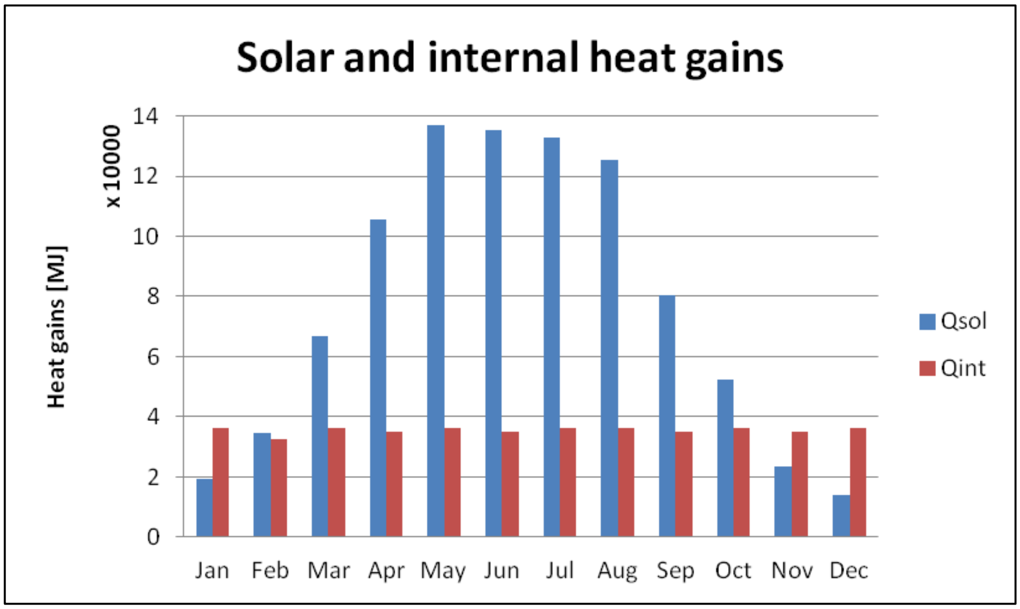

Figure 3.1 Heat gains from internal and solar sources calculated according to EN 13790

3.3.1 Internal heat gains

The resulting internal heat gains from occupants, lighting and appliances were calculated taking into account the selections presented in Table 2.4. The results are shown in Table 3.3.

Table 3.3 Internal heat gains

$\Phi_{int,occupants}$	2.00	W/m^2
$\Phi_{int,lighting}$	5.00	W/m^2
$\Phi_{int,appliances}$	1.00	W/m^2
Floor area	2525	m^2
Occupancy fraction	0.67	-
Φ_{int}	**13469**	**W**

3.3.2 Solar heat gains

According to EN 13790, the first step to calculating the solar heat gains is to determine the effective solar collecting area for the glazed element. For the purpose of this calculation it is easier to group glazed elements according to their orientation and slope. Table 3.4 shows the selected parameters used to determine the effective solar collecting area for the glazed elements described in section 2.1.2.

Table 3.4 Effective collecting area of glazed elements

Parameter	Symbol	Skylights	Windows / gates	Unit
Orientation/ slope	-	- / 0°	East / 90°	-
Transmittance	g_n	0.75	0.75	-
Correction factor for transmittance	F_W	0.90	0.90	-
Frame area fraction	F_F	0.00	0.00	-
Area of the element	$A_{w,p}$	357.84	36.50	m^2
Effective collecting area	A_S	**241.54**	**24.64**	m^2

Tables 3.5 and 3.6 present the monthly solar heat gains Q_{sol} corresponding to the elements in the east façade and ceiling respectively, based on the average daily solar heat gains Φ_{sol}.

Table 3.5 Monthly solar heat gains - East façade

Month	days	t	H_{sol}	$\Phi_{sol,East}$	$Q_{sol,East}$
-	-	h	$kWh.m^{-2}$	W	MJ
January	31	744	14.10	467	1251
February	28	672	25.50	935	2262
March	31	744	46.90	1553	4160
April	30	720	74.20	2539	6581
May	31	744	87.00	2881	7716
June	30	720	90.00	3080	7983
July	31	744	84.10	2785	7459
August	31	744	80.40	2662	7131
September	30	720	53.30	1824	4727
October	31	744	38.70	1282	3432
November	30	720	18.00	616	1597
December	31	744	11.20	371	993
Total					**55292**

Table 3.6 Monthly solar heat gains – Skylights on the ceiling

Month	days	t	H	$\Phi_{sol,Ceiling}$	$Q_{sol,Ceiling}$
-	-	h	kWh.m^{-2}	W	MJ
January	31	744	20.80	6753	18087
February	28	672	37.00	13299	32173
March	31	744	72.20	23440	62782
April	30	720	113.80	38177	98955
May	31	744	148.80	48308	129389
June	30	720	146.20	49046	127128
July	31	744	144.30	46847	125476
August	31	744	136.20	44218	118433
September	30	720	87.10	29220	75738
October	31	744	56.50	18343	49130
November	30	720	25.20	8454	21913
December	31	744	14.90	4837	12956
Total					**872160**

3.4 Thermal capacitance of the building

In order to calculate the utilization factor as well as to account for the effects of intermittent heating, it is necessary to determine the thermal capacity of the building. According to EN 13790, the heat capacity is calculated by summing the heat capacities of all the building elements in direct thermal contact with the internal air of the zone under consideration [1].

It is important to note that the standard indicates a maximum thickness to be considered for the heat capacity depending on the application. This maximum thickness is 0.1 m when calculating the heat capacity for the effects of intermittence and 0.03 m for the calculation of the gain utilization factor. The resulting heat capacities of the elements are presented in Table 3.7 (for the calculation of gain utilization factor) and Table 3.8 (for the effects of intermittent heating.

Table 3.7 Thermal capacitance for calculation of gain utilization factor

Element type	Area	Density	Specific heat	Effective depth	Cm
-	m2	kg/m3	J/(kg.K)	m	J/K
Floor	2525	2400	1000	0.10	606000000
Ceiling	2525	160	840	0.10	33936000
External walls	1207	1750	960	0.10	202776000
Internal partitions	342	1750	960	0.10	57456000
Internal partitions	108	881	1000	0.03	2845454
Glazed elements	431	2500	840	0.02	13576500
Total					**9.17E+08**

Table 3.8 Thermal capacitance for taking into account the effects of intermittence

Element type	Area	Density	Specific heat	Effective depth	Cm
-	m2	kg/m3	J/(kg.K)	m	J/K
Floor	2525	2400	1000	0.03	181800000
Ceiling	2525	160	840	0.03	10180800
External walls	1207	1750	960	0.03	60832800
Internal partitions	342	1750	960	0.03	17236800
Internal partitions	108	881	1000	0.03	2845454
Glazed elements	431	2500	840	0.02	13576500
Total					**2.86E+08**

3.5 Gain utilization factor

Once the heat losses and heat gains from the building are established, it was necessary to calculate the annual heat consumption. In order to do this the dynamic effects must be taken into account by introducing the gain utilization for heating $\boldsymbol{\eta_{gn}}$ as a function of the heat balance ratio $\boldsymbol{\Upsilon_H}$ and the building inertia. A number of parameters were selected and calculated and they are presented in Table 3.9.

Table 3.9 Parameters to account for dynamic effects

Parameter	Symbol	Value	Unit
Internal coupling coefficient	$\mathbf{H_m}$	5328	W/K
Heat capacity	$\mathbf{C_m}$	9.17E+08	J/K
Time constant of the building	$\boldsymbol{\tau_H}$	47.79	H
Reference time constant	$\boldsymbol{\tau_{H0}}$	15.00	H
Dimensionless num. parameter acc to $\boldsymbol{\tau_H}$	$\mathbf{a_H}$	4.19	-
Dimensionless reference parameter	$\mathbf{a_{H0}}$	1.00	-

The internal coupling coefficient represents the sum of the overall transmission and ventilation heat transfer coefficients for the building. The thermal capacitance calculation is discussed in section 3.4.

3.6 Effects of intermittent heating

In order to take into account the effects of intermittent heating it was necessary to determine the dimensionless factor $\alpha_{red,H}$. This factor represents a reduction factor for intermittent heating that was determined by taking into account the hours of the occupied period, the building time constant and the heat balance ratio. The parameters for this calculation are displayed in Table 3.10. It's important to note that the thermal capacitance for this part of the calculation is different due to the maximum effective thickness of the building elements, as mentioned in section 3.4.

Table 3.10 Parameters to account for intermittent heating

Parameter	Symbol	Value	Unit
Corrected heat capacity	C_m	2.86E+08	J/K
Time constant of the building	τ_H	14.94	H
Reference time constant	τ_{H0}	15.00	H
Dimensionless num. param. acc to τ_H	a_H	2.00	-
Dimensionless reference parameter	a_{H0}	1.00	-
Empirical correlation factor	$b_{red,H}$	3.00	-
Fraction of heating period	f_H	0.67	-

3.7 Annual energy consumption for heating

Finally, the monthly balance was calculated and the summation obtained to estimate the value of annual heat consumption $Q_{H,n}$. This balance is presented in Table 3.11.

Table 3.11 Heat consumption balance according to EN 13790

Month	Q_{gn}	Q_{ls}	Υ_H	η_{gn}	$Q_{H,n,N}$	$\alpha_{red,H}$	$Q_{H,n}$
-	MJ	MJ	-	-	MJ	-	MJ
January	55412	278228	0.20	1.00	222868	0.80	178290
February	67019	258633	0.26	1.00	191789	0.74	141876
March	103016	206258	0.50	0.97	106142	0.67	70761
April	140447	138976	1.01	0.80	26212	0.67	17475
May	173180	71157	2.43	0.40	1023	0.67	682
June	170022	32765	5.19	0.19	27	0.67	18
July	169010	9750	17.34	0.06	0	0.67	0
August	161639	5363	30.14	0.03	0	0.67	0
September	115376	64530	1.79	0.54	2627	0.67	1751
October	88637	137301	0.65	0.94	54275	0.67	36183
November	58420	217845	0.27	1.00	159598	0.73	116613
December	50024	244996	0.20	1.00	195023	0.79	155030
Total [MJ]					959583		718679

3.8 Considerations for large space buildings

The standard is intended for use on residential or non-residential buildings, with no limits in terms of dimensions or use. During the calculation procedure there were no special considerations or correction factors that take into account the dimensions of the building.

CHAPTER 4

CALCULATION OF HEATING ENERGY CONSUMPTION ACCORDING TO CIBSE TM41

The present chapter describes the steps taken to obtain the annual heating energy consumption for the case study building according to CIBSE TM41. The possible approaches and selection is discussed followed by the different parts of the calculation. The switch-on times and temperatures for the heating system are discussed and how they were used to determine the monthly base temperature. It is explained how mean degree-hours were used to obtain a mathematically precise number of degree hours per month in order to finally calculate the heat consumption of the building.

4.1 General approach

CIBSE TM41 describes two different approaches to calculate heating consumption, one intended for continuously heated buildings and another for intermittent heating. As described in section 2.1.4, the case study building is not in continuous operation and therefore requires intermittent heating. According to the intermittent approach, the calculation performed used an adjusted base temperature in order to compensate for the effects of the building mass over the intermittence of the heating.

4.2 Thermal capacitance and time constant

CIBSE TM41 deals with building energy storage and intermittent heating by proposing the calculation of the mean internal temperature of the building and its use in the determination of the adjusted base temperature. This mean internal temperature is directly related to the building's time constant. The building time constant to account for intermittent heating was determined in the same manner as in the calculation performed using EN 13790 (see section 3.6). It is important to note that the parameters relating to thermal capacitance of the building, as is the time constant, depend on the application for which they are being calculated (see Section 3.4).

4.3 Switch-on temperature

In the determination of the temperature at which the heating system must be switched on θ_{So}, an important factor is the mean overnight temperature θ_o, which can range between 0.2 C to 1.5 C below the mean daily temperature. However, as this data is not readily available, it was determined that the mean daily temperature would be used instead. "In practice, using the overall mean monthly temperature makes very little difference (generally less than 1%) to the final energy calculations [2].

The heat load of the building was determined as an input in the calculation of the switch on temperature, which was then an input to calculate the mean internal temperature $\theta_{i,mean}$. Table 4.1 shows the internal switch on temperature for each month.

Table 4.1 Monthly switch-on temperatures

Month	$\theta_e = \theta_o$	θ_{So}
-	C	C
January	-1.50	14.16
February	-2.07	14.22
March	3.55	14.13
April	7.94	14.78
May	13.01	16.15
June	15.63	17.06
July	17.32	17.72
August	17.62	17.85
September	13.33	16.25
October	8.38	14.88
November	2.23	14.05
December	0.83	14.03

4.4 Switch-on time and mean internal temperature

For each month, an average switch on time was determined. The real switch-on times will vary each night with the external temperature; however, a representative switch-on temperature and time were calculated for each month in order to determine the base temperature. Figure 4.1 shows the progression of the internal temperature with time for the representative month of January, it is easy to identify that the preheat time is greater than the actual time the heating system is switched off.

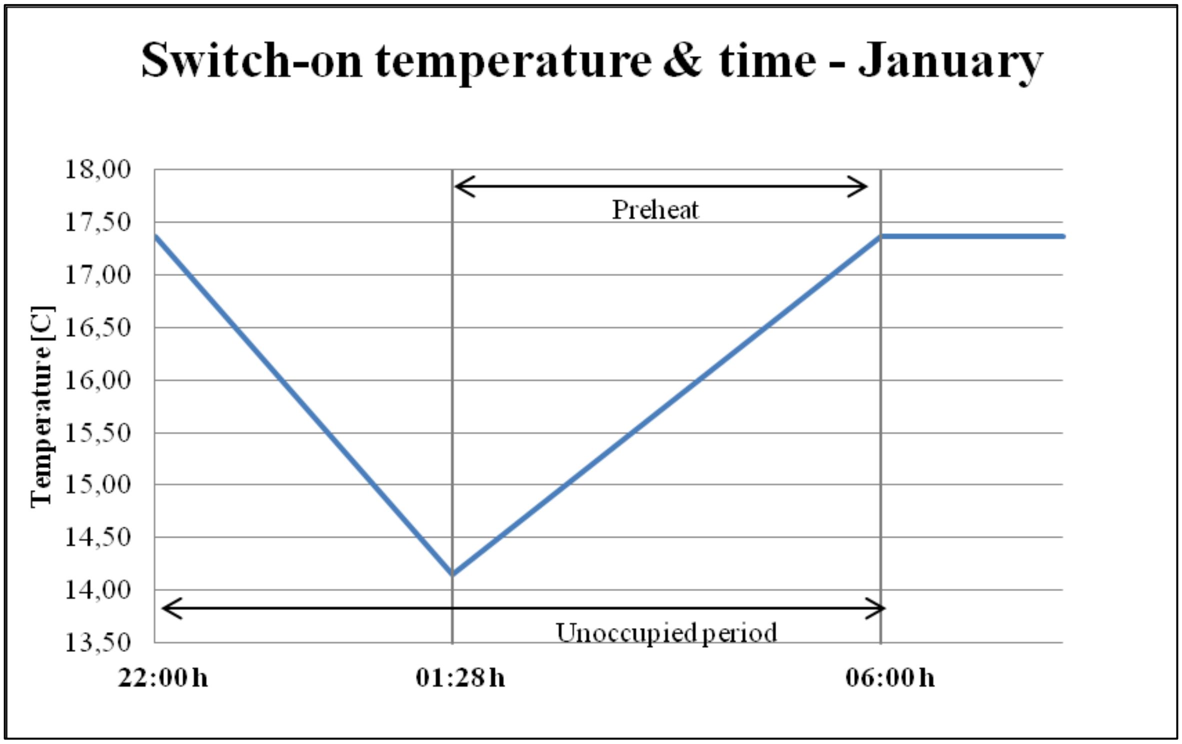

Figure 4.1 Progression of the average internal temperature overnight for the month on January

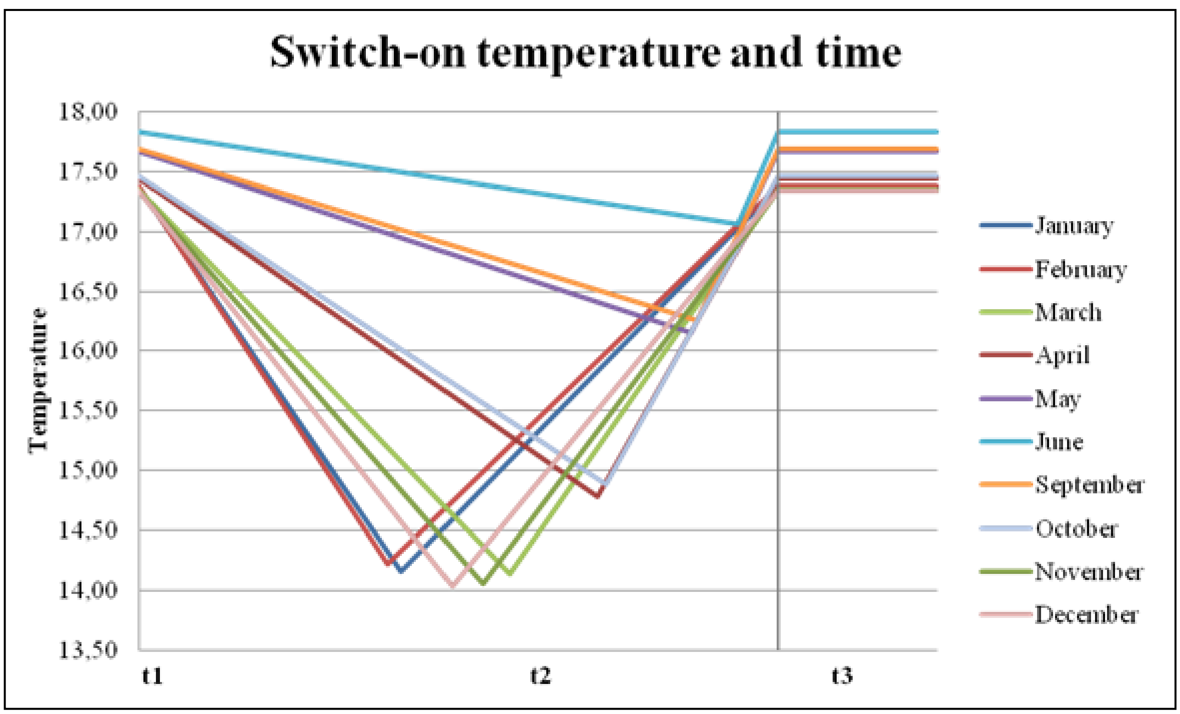

Figure 4.2 Progression of the average internal temperature overnight for each month

4.5 Base temperature

In order to determine the base temperature θ_b it was necessary to determine the corrected monthly heat gains. The corrected heat gains Q_{gn} are a product of the heat gains Q_{gn}' (solar and internal) and the gain utilization factor. The procedure proposed by CIBSE TM41 to obtain the heat gains, losses and gains is the same as the one followed for the calculation according to EN 13790, if less detailed. The values used are the same as the ones determined in the aforementioned calculation and can be found in Section 3.5. The significant values for the calculation of, and finally the monthly base temperature θ_b values are shown in Table 4.2.

Table 4.2 Base temperature for each month and relevant calculation data

Month	$\theta_{i,mean}$	Q_{gn}'	Q_{ls}	η_{gn}	Q_{gn}	θ_b
-	C	kW	kW	-	kW	C
January	17.4	20.69	103.88	1.00	20.67	13.5
February	17.4	27.70	106.91	1.00	27.63	12.2
March	17.3	38.46	77.01	0.97	37.38	10.3
April	17.4	54.18	53.62	0.80	43.50	9.3
May	17.7	64.66	26.57	0.40	26.18	12.8
June	17.8	65.59	12.64	0.19	12.63	15.5
July	17.9	63.10	3.64	0.06	3.64	17.3
August	18.0	60.35	2.00	0.03	2.00	17.6
September	17.7	44.51	24.90	0.54	23.88	13.2
October	17.5	33.09	51.26	0.94	31.00	11.6
November	17.3	22.54	84.05	1.00	22.47	13.1
December	17.3	18.68	91.47	1.00	18.66	13.8

4.6 Calculation of degree-days

The degree-days were calculated using the mean degree-hours method since it is described as the most mathematically precise method in the standard. The positive values of the hourly temperature differences between external temperature and base temperature were determined and then divided by 24. For each month the difference were summed to obtain the number of degree days in that month. A graph representing the monthly degree-days is presented in Figure 4.3. The total number of degree-days in the year is 2300.

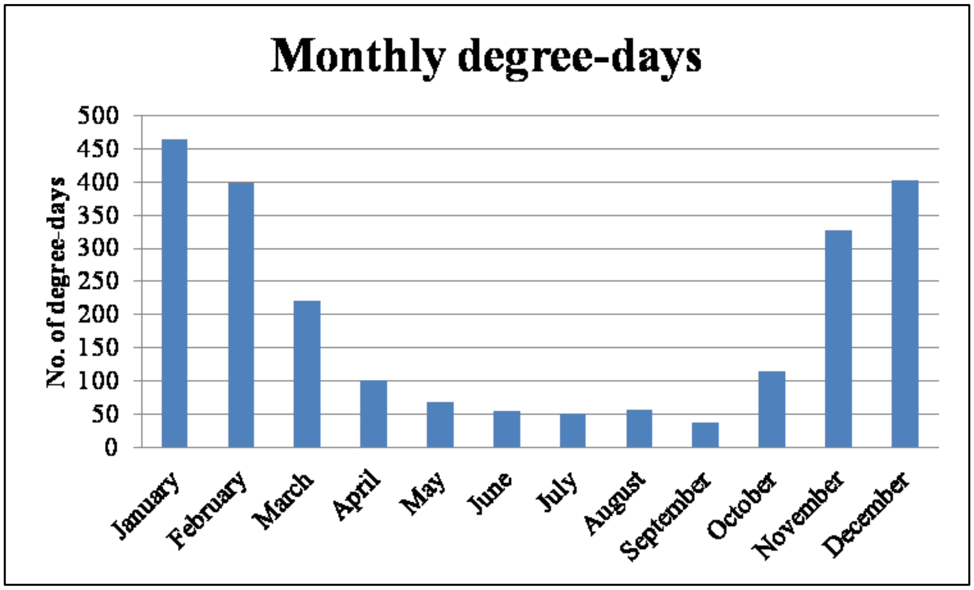

Figure 4.3 Degree-days per month using mean degree-hours

4.7 Annual heating energy consumption

Once the number of degree-days was determined, the heat consumption for each month was calculated by simply obtaining the product of the degree-days times the building's overall heat transfer coefficient. The sum of the monthly values led to the final annual heat consumption of the case study building according to CIBSE TM41.

Table 4.3 Monthly and annual heat consumption according to CIBSE TM41

Month	D_m	$Q_{H,n}$
-	-	kW.h
January	464	59395
February	399	51064
March	221	28197
April	101	12954
May	68	8691
June	55	7049
July	52	6594
August	58	7411
September	38	4817
October	114	14617
November	327	41802
December	403	51554
Total	**2300**	**294143**

4.8 Considerations for large space buildings

The standard presents a very general and simple approach to calculate degree days and heat consumption, with no limits in terms of dimensions or use or the building. During the calculation procedure there were no special considerations or correction factors that take into account the dimensions of the building.

CHAPTER 5

CALCULATION OF ADDITIONAL HEATING ENERGY CONSUMPTION ACCORDING TO EN 15316-2-1

The present chapter describes the calculation of the heat losses of the heat emission system. First, available methods and the selection of the one used is discussed. Then, the selection of the parameters required is presented, such as efficiencies and factors required for the calculation. Finally, the values of the heat losses are presented in Table 5.2.

5.1 Method

The EN 15316-2-1 standard proposes two different calculation methods to determine the heat losses for heat emission and control; a method using efficiencies and a method using an equivalent internal temperature increase. It also allows the possibility to select the calculation period, yearly, monthly, weekly, etc.

The calculation realized was based on monthly values using the method using efficiencies. The simple calculation consists on calculating the sum of the losses of the heat emission system and the auxiliary energy of the system. The losses are determined by applying efficiencies and correction factors to the net heating energy for each heating period as shown in Equation 5-1.

$$Q_{l,em} = \left(\frac{f_{Radiant} * f_{int} * f_{hydr}}{\eta_{l,em}} - 1 \right) * Q_h \qquad \text{Eq. 5-1}$$

As stated in the standard, it is necessary to know the net energy demand $\mathbf{Q_h}$ for space heating beforehand. The standard required this information to be calculated according to EN 13790, however, the calculation was performed using both the net energy demand calculated according to EN 13790 (see Chapter 3) and also according to CIBSE TM41 (see Chapter 4).

5.2 Efficiencies

The required efficiencies were selected from Appendix A of EN 15316-2-1 according to the type of heat emission, type of control system and height of the building. Figure 5.1 displays the table obtained from the standard with the selections for each case.

Parameters			Part efficiencies					
			η_L				η_C	η_B
			4 m	6 m	8 m	10 m		
Space temp. control	Uncontrolled						0,80	
	Two-step controller						0,93	
	P controller (2 K)						0,93	
	P controller (1 K)						0,95	
	PI controller						0,97	
	PI controller with optimum tuning						0,99	
Heating systems	Warm air heating	Air outlet at the side	0,98	0,94	0,88	0,83		1
	Air distribution with normal induction ratio	Air outlet above	0,99	0,96	0,91	0,87		1
	Warm air heating	Air outlet at the side	0,99	0,97	0,94	0,91		1
	Air distribution with controlled vertical recirculation	Air outlet above	0,99	0,98	0,96	0,93		1
	Ceiling mounted radiant panels		1,00	0,99	0,97	0,96		1
	Radiant tube heaters		1,00	0,99	0,97	0,96		1
	Luminous radiant heaters		1,00	0,99	0,97	0,96		1
	Underfloor heating (with a high level of thermal insulation)		1,00	0,99	0,97	0,96		
		Integrated floor heating						0,95
		Thermally decoupled underfloor heating						1

Figure 5.1 Selection of efficiencies [3]

5.3 Correction factors

The following correction factors were selected for the calculation:

- factor for the hydraulic equilibrium: 1;
- factor for intermittent operation: 1;
- factor for the radiation effect: 0.85 (for ceiling-mounted radiant panels, bright radiators, dark radiators and floor heating).

5.4 Energy losses of the heat emission system

Taking into consideration the selected factors and efficiencies, the monthly energy losses were calculated and are presented in Table 5.1.

Table 5.1 Heat losses of the heat emission system

		EN 13790		CIBSE TM41	
Month	**t**	Q_h	$Q_{l,em}$	Q_h	$Q_{l,em}$
-	**h**	**kW.h**	**kW.h**	**kW.h**	**kW.h**
January	744	49525	1832	59395	2198
February	672	39410	1458	51064	1889
March	744	19656	727	28197	1043
April	720	4854	180	12954	479
May	744	189	7	8691	322
June	720	5	0	7049	261
July	744	0	0	6594	244
August	744	0	0	7411	274
September	720	486	18	4817	178
October	744	10051	372	14617	541
November	720	32393	1199	41802	1547
December	744	43064	1593	51554	1907
Total		199633	7386	294143	10883

5.5 Auxiliary energy

The auxiliary energy for the heat emission equipment was also determined. For buildings with a height above 4 m, the standard value of auxiliary energy of fans and control system of emitters may be obtained from a table. Figure 5.2 presents the selection of the parameters that influence the requirement of auxiliary energy.

	Influence parameters	Power W
$P_{h,aux}$ Directly heated heat generator (installed in the working space)	Bright radiators (control and regulation)	25 (per unit)
	Dark radiators up to 50 kW (control, regulation and fan for combustion air supply)	80 (per unit)
	Dark radiators above 50 kW (control, regulation and fan for combustion air supply)	100 (per unit)
	Warm air generator with atmospheric burner and recirculation air axial fan (control, regulation and fan for combustion air supply)	$0.014 \cdot Q_{h,b}$
	Warm air generator with fan-assisted burner and recirculation air radial ventilator (control, regulation and fan for combustion air supply, fan for warm air supply)	$0.022 \cdot Q_{h,b}$

Figure 5.2 Selection of Power for auxiliary energy of emission system [3]

5.6 Total energy losses of the heat emission system

Losses due to the efficiency of the system and due to the requirement of auxiliary energy $\mathbf{Q_{h,aux}}$ are summed. Table 5.2 presents the final value of the losses on a monthly basis according to the net heating energy calculated by the methods presented in the previous chapters.

Table 5.2 Results of calculation of EN 15316-2-1

		EN 13790			CIBSE TM41		
Month	$\mathbf{Q_{h,aux}}$	$\mathbf{Q_h}$	$\mathbf{Q_{l,em}}$	$\mathbf{Q_{h,total}}$	$\mathbf{Q_h}$	$\mathbf{Q_{l,em}}$	$\mathbf{Q_{h,total}}$
-	**kWh**	**kW.h**	**kW.h**	**kWh**	**kW.h**	**kW.h**	**kWh**
January	99	49525	1832	51456	59395	2198	61691
February	90	39410	1458	40958	51064	1889	53043
March	99	19656	727	20482	28197	1043	29340
April	96	4854	180	5130	12954	479	13529
May	99	189	7	296	8691	322	9112
June	96	5	0	101	7049	261	7406
July	99	0	0	99	6594	244	6937
August	99	0	0	99	7411	274	7784
September	96	486	18	600	4817	178	5091
October	99	10051	372	10522	14617	541	15257
November	96	32393	1199	33687	41802	1547	43445
December	99	43064	1593	44756	51554	1907	53561
Total				**208188**			**306195**

CHAPTER 6

RESULTS AND ANALYSIS

The present chapter presents the most relevant results of the calculations and a brief discussion about their relevance. First, the proposed methodology to calculate the heating energy consumption for large space buildings is described. Later, the results from EN 13790 and CIBSE TM41 as well as the heat losses of the emission system are discussed. Finally, the factors that influence the discrepancies between the results using different calculation methods are discussed and a theoretical comparison is presented to analyze the effect of these factors.

6.1 Heating energy consumption for large space buildings

The calculation of heating energy consumption for large space buildings may be performed by a combination of two different standards. One main standard will provide an input for EN 15316-2-1, by means of which the losses of the heating system may be determined. These losses depend on a number of factors, the most important being the building height and the type of emission system (radiant heating). EN 15316-2-1 indicates that the net heating consumption (without associated losses) must be obtained from the calculation using EN 13790, however, CIBSE TM41 presents a similar, and even simpler method to perform the calculation. The calculation of heating energy consumption to be used as input for EN 15316-2-1 may instead be performed using CIBSE TM41, provided the difference between results is considered. Figure 6.1 presents a diagram of how these standards could be used to obtain the total annual energy consumption for a large space building.

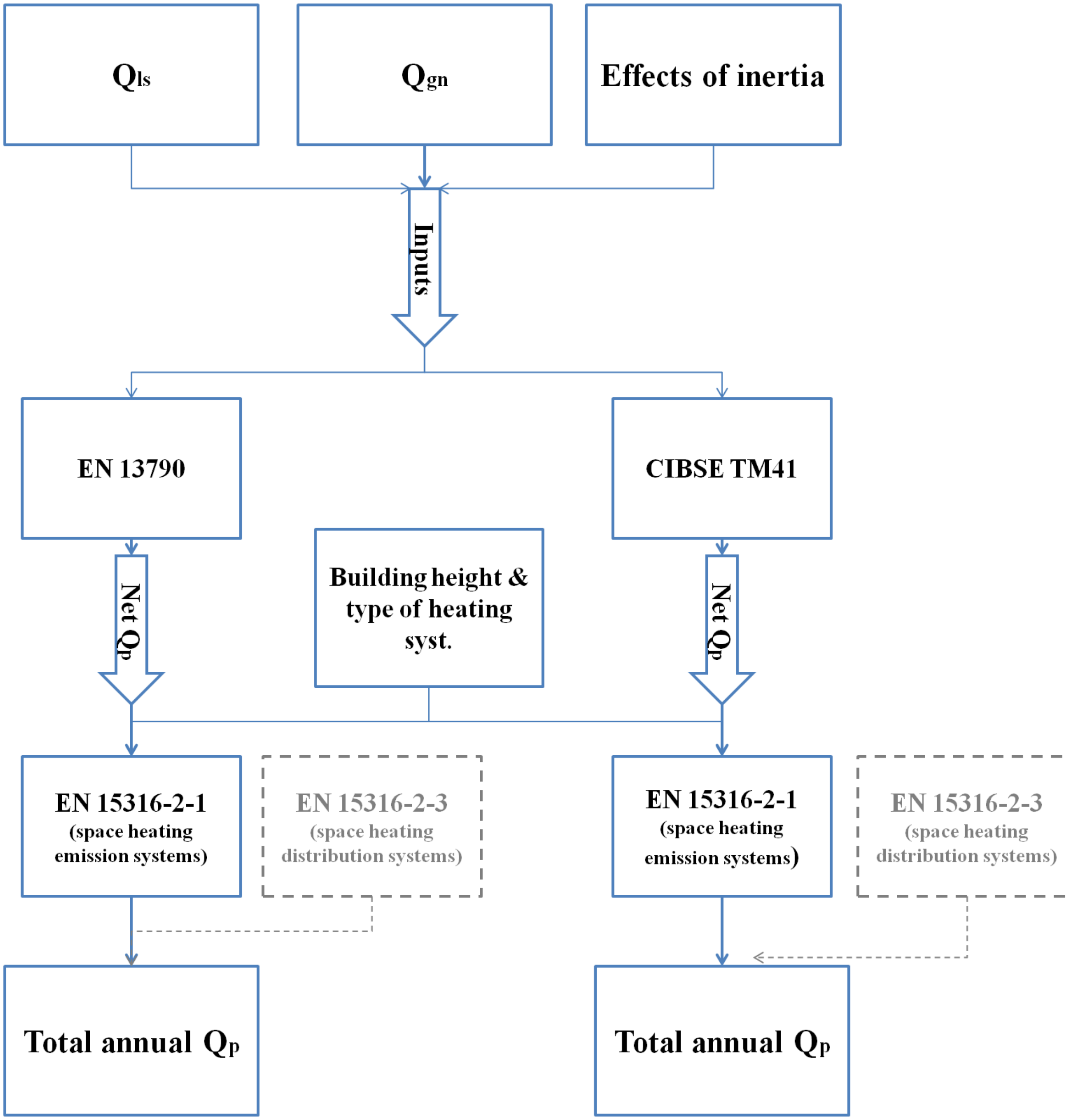

Figure 6.1 Calculation flow chart – EN 15316-2-3 not considered for this thesis

6.2 Heating energy consumption according to EN 13790 and CIBSE

The monthly heating energy consumption for the Case Study obtained by means of the calculations presented in EN 13790 and CIBSE is displayed in Figure 6.2.

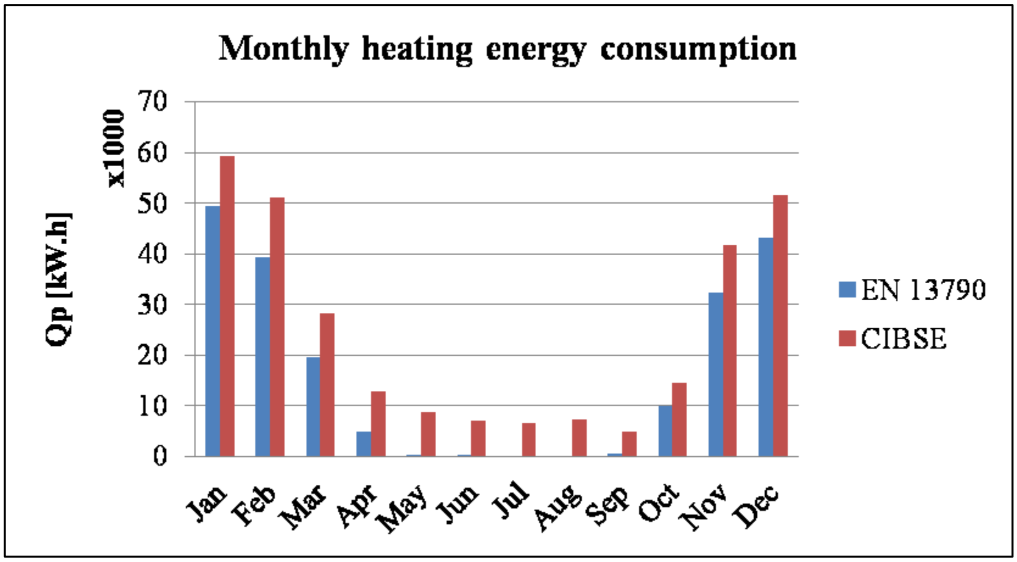

Figure 6.2 Comparison of monthly energy consumption according to EN 13790 and CIBSE

It can be seen that the calculation according to CIBSE TM41 produces higher values for every month, with differences ranging from 4300 kWh in September, to 11600 kWh in February.

The same graph, but including the heat losses calculated by means of EN 15316-2-1 is displayed in Figure 6.3. As the losses are directly proportional to the net heating energy, the differences are higher, ranging from 4400 kWh to 12000 kWh. Also, in Table 6.1 are presented the annual values and the percentage difference between the calculations using the different standards.

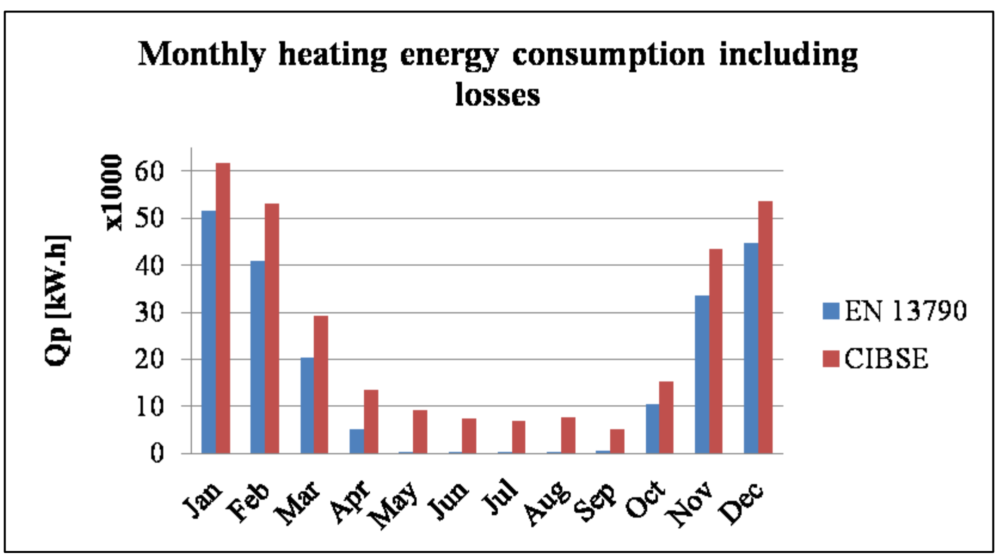

Figure 6.3 Monthly heating energy consumption including losses of the heat emission system

Table 6.1 Percentage difference in annual heat consumption

	Net Q_p	Q_p + losses*
	kW.h	kW.h
EN 13790	199633	208188
CIBSE TM41	294143	306195
Difference	38.3%	38.1%

It is relevant to note that when performing the calculation using CIBSE TM41, there is heating energy consumption during the months of July and August. The results of EN 13790 indicate no heating in the same months. This difference is due to high base temperatures of these months, which are higher than night time temperatures.

As all the input data in the calculations is the same, including the heat gains and heat losses, the effects of other aspects of the calculation must be analyzed to determine the reasons for this difference nearing 40%.

6.3 Gain utilization factor

A utilization factor for the internal and solar heat gains takes account for the fact that only part of the internal and solar heat gains is utilized to decrease the energy need for heating, the rest leading to an undesired increase of the internal temperature above the set-point. This factor is used in both EN 13790 and CIBSE TM41 as a part of the calculation; however, as the calculation methods are different, the way this factor is taken into account also varies with each calculation.

The final heating need according to EN 13790 is simply the heat losses (transmission and ventilation) minus the utilized gains. The CIBSE TM41 standard makes use of the utilization gain in the calculation of the base temperature. Table 6.2 displays the equations that are used in the calculations. It is important to note that the determination of the utilization factor is the same for both standards, using the second and third equations in the first column of the table below.

Table 6.2 Utilization factor equations

EN 13790	CIBSE TM41
$Q_H = Q_{ls} - Q_{gn} * \eta_g$	$Q_H = \frac{24 * U' * D_d}{\eta_{syst}}$
$\eta_g = \frac{1 - \Upsilon_H{}^{a_H}}{1 - \Upsilon_H{}^{a_H+1}}$	$D_d = \frac{\sum_{j=1}^{24}(\theta_b - \theta_o)}{24}$
$\Upsilon_H = \frac{Q_{gn}}{Q_{ls}}$	$\theta_b = \bar{\theta}_i - \frac{Q_{gn} * \eta_g}{U'}$
	$\eta_g = \frac{1 - \Upsilon_H{}^{a_H}}{1 - \Upsilon_H{}^{a_H+1}}$
	$\Upsilon_H = \frac{Q_{gn}}{Q_{ls}}$

6.4 Effects of intermittent heating

In EN 13790, the effect of thermal inertia in case of intermittent heating is taken into account as a reduction of the calculated heating consumption. Equations 1 and 2 are how the effect of intermittency is considered in EN 13790.

$$a_{red} = 1 - b_{red} * \frac{\tau_{H,o}}{\tau} * \Upsilon_H * (1 - f_H) \qquad \text{Eq. 6-1}$$

$$Q_H = a_{red} * Q_h + (1 - a_{red}) * Q_{H,B} \qquad \text{Eq. 6-2}$$

For the CIBSE TM41, the intermittency is taken into account from the beginning of the calculation by the determination of the switch-on temperature, the mean internal temperature and finally the base temperature, as shown in Equation 3. Then, the energy consumption occurs when the outdoor temperature is above the base temperature.

$$\theta_b = \bar{\theta}_i - \frac{Q_{gn}}{U'} \qquad \text{Eq. 6-3}$$

6.5 Effects of building thermal inertia

From the results, and the topics discussed in sections 6.2 and 6.3, it is reasonable to assume that the building's thermal inertia has a different effect in each of the calculation methods (EN 13790 and CIBSE TM41). To analyze this effect, both calculations were performed on different building types. Table 6.3 displays the values of annual heating energy consumption for different buildings; these buildings have the same dimensions, and weather conditions as the Case Study, but different parameters that influence the effects of building inertia. The values of the parameters for building inertia were taken from Table 12 in EN 13790, which shows default values for different building classes which may be used for the calculation. The trend shows that heavier buildings will produce more similar results when performing the calculation using different methods.

Table 6.3 Theoretical comparison - Effects of building inertia over annual heating energy consumption

Building class	C_m*	H_m*	CIBSE TM41	EN13790	Difference
-	MJ/K	kW/K	MW/h	MW/h	%
Very light	1.52E+05	23.23	1478	1186	22%
Light	2.10E+05	23.23	1540	1219	23%
Medium	3.13E+05	23.23	1620	1321	20%
Heavy	4.92E+05	25.00	1829	1534	18%
Very heavy	7.02E+05	26.26	1981	1702	15%

*** = values obtained from Table 12 of EN 13790**

It is important to note that the values in this table are default values which depend on the surface area of building elements. As this standard is general and has no considerations for large space buildings, most likely the default values in the table are for average height buildings, 3 m – 4 m. This indicates that in order to take these values for a calculation for a large building, a correction should be considered to account for the height.

The results are graphically compared in the graph in Figure 6.4.

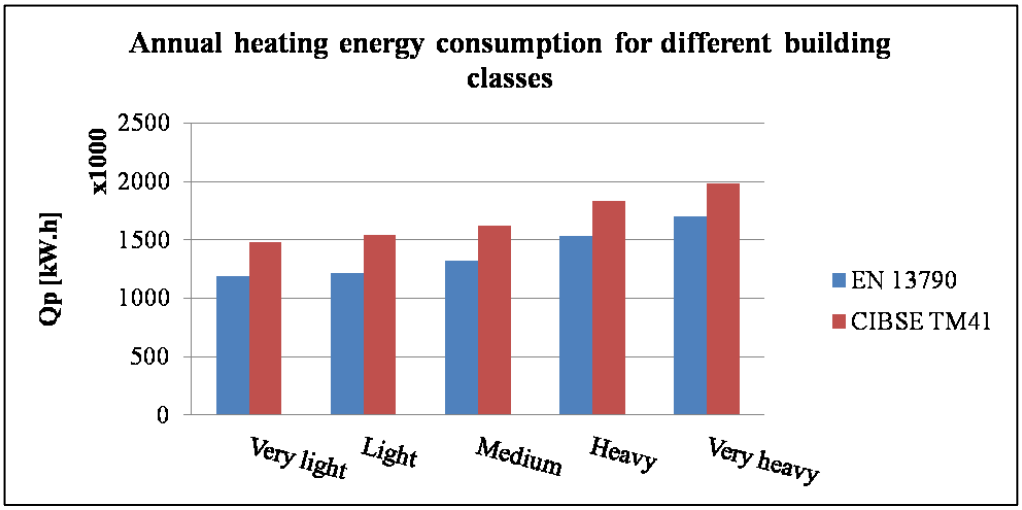

Figure 6.4 Theoretical comparison - Annual heating energy consumption for different building classes.

CONCLUSIONS

The calculation of annual heating energy consumption by the methods proposed in EN 13790 and CIBSE TM41 was performed and later extended to take into account the losses of the heat emission system using the calculation of EN 15316-2-1. After analyzing the results it is possible to come to the following conclusions.

- The EN 13790 standard provides a calculation procedure to determine the annual heating energy consumption for residential and non-residential buildings, however, there are no special considerations that take into account the non-uniform temperature distribution due to uncommon building height (> 4 m).
- The CIBSE standard also provides a calculation procedure to determine the annual heating energy consumption for residential and non-residential buildings using degree-days, this method is more simplified than the one in EN 13790 and also doesn't include special considerations for large space buildings.
- It is possible to obtain more accurate values of heating energy consumption of large space buildings by using one of the calculation methods proposed in standard EN 15316-2-1, which takes into account the heating losses of the emission system and also considers a correction for heights above 4 m.
- The calculation method proposed in EN 15316-2-1 indicates that the heating consumption (monthly, seasonal or annual), should be obtained using EN 13790. However, CIBSE TM41 also provides a calculation method for the heating consumption; therefore, the results from CIBSE TM41 may also be used as inputs for EN 15316-2-1.
- The results of EN 15316-2-1 are linked to the calculation of heating energy consumption, so the error is carried from the calculation of the net heating consumption to the total heating consumption (including losses of the emission system, effects of non-uniform temperature distribution and efficiencies of different radiant heating systems).
- A simple flowchart was developed to display the procedure in which the calculation of heating energy consumption of large space buildings may be performed by using

the combination of either EN 13790 or CIBSE TM41 and EN 15316-2-1 (section 6.1).

- The calculation of net annual heating energy consumption was performed using two different standards. The results obtained by using EN 13790 and CIBSE TM41 presented a difference of 38% even though the inputs used for both calculations were the same.
- After an analysis of the equations both methods, it was assumed that the discrepancies occur due to the way each calculation method takes into account the heat accumulation of the building.
- The effects of intermittent heating affect each calculation method in different proportions.
- A theoretical comparison was performed by calculating the annual heating energy consumption of five buildings, each of a different building class. It was observed that the percentage difference between the calculations using EN 13790 and CIBSE TM41 decreases as the building thermal capacitance increases. From the results obtained, it is possible to assume that the results will be more similar for buildings in the class “very heavy.
- It would be beneficial to perform the calculations for different case studies where the heating energy consumption has been measured in order to determine the accuracy of each calculation method. It may also be helpful in determining whether one of the two calculation methods studied is more or less accurate depending on the building class.

In summary, it is possible to calculate the annual heating energy consumption of a large space building by following the simple calculation methods presented in EN 13790 or CIBSE TM41. These results may be complemented with the calculation of energy losses of the emission system and effects of non-uniform temperature distribution and efficiencies of radiant heating systems by following the methods described in EN 15316-2-1. Special attention must be paid when considering the effects of heat accumulation and intermittency.

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