EINSTEIN

D5.6 – Decision Support Tool for stakeholders for selection, design and evaluation of STES

Project acronym:	EINSTEIN
Project full title:	EFFECTIVE INTEGRATION OF SEASONAL THERMAL ENERGY STORAGE SYSTEMS IN EXISTING BUILDINGS
Grant agreement no.:	284932
Doc. Ref.:	EINSTEIN-WP5-Task 5.6-RTD-
Responsible:	DAPP
Author(s):	DAPP, TECNALIA, SOLITES, ACCIONA, MOSTOSTAL, ULSTER, USTUTT, ICOP
Date of issue:	
Status:	
Security:	PU

Change control:

Version and date	Changes
V1 – 27/02/2015	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

A_{SC}	Solar Collector Area
ATES	Aquifer Thermal Energy Storage
B	Boiler
B_{eff}	Boiler efficiency
BIO%	Percentage Of Biomass Use
BTES	Borehole Thermal Energy Storage
c_1	Specific Solar Collector Area
c_2	Specific STES Volume
c_3	H/D ratio
CAPEX	Total investment cost
C_{BIO}	Biomass Cost
C_{EL}	Electricity cost
C_{GAS}	Gas Cost
c_{HP}	Heat Pump Specific Cost
C_{HP}	Total heat pump cost
CO_2	Carbon Dioxide
Configuration A	Distributed generation
Configuration B	Centralized generation
COP	Coefficient Of Performance
c_{sc}	Solar Collector Specific Cost
C_{SC}	Total solar collector cost
c_{STES}	STES Specific Cost
C_{STES}	Total STES cost
DH	District Heating
DHN	District Heating Network
DHW	Domestic Hot Water
D_{pipes}	DH Pipe Internal Diameter
DST	Decision Support Tool
EA_n	Energy accumulated in the STES per day
EEA	European Environmental Agency
EGG	Expended Glass Granules
ETC	Evacuated Tubular Collector
$F_{CO2,eq}$	CO_2 Equivalent Emission reduction indicator
FGG	Foam Glass Gravel

FPC	Flat Plate Collector
FPCh	High Performing Flat Plate Collector
FPCm	Medium Performing Flat Plate Collector
GAS%	Percentage Of Gas Use
G_T	Total global irradiance on the collector surface
H	Irradiation on a Tilted Surface
HC	Heat Cost
HDD_{15}	Heating Degree Days
HP	Heat Pump
H_{pump}	DH Pump Hydraulic Head
HT	High Temperature
HT%	Percentage of Demand at High Temperature
HVAC	Heating, Ventilating and Air Conditioning
k_1	Solar Collector 1st order heat loss coefficient
k_2	Solar Collector 2nd order heat loss coefficient
k_f	Permeability
L	DH Network distance
LT	Low Temperature
LT%	Percentage of Demand at Low Temperature
$\dot{m}_{DH,max}$	Maximum DH network flow
n	Number of days
$n_{dwelling}$	Number of dwelling
PE	Primary Energy
$P_{EL,eff}$	DH Pump Electrical Efficiency
PE_{saving}	Primary Energy Savings
PTES	Pit Thermal Energy Storage
PUR	Polyurethane
$Q_{boiler,HP}$	Boiler heat load (preheated HP) per day
$Q_{boiler,noHP}$	Boiler heat load without HP per day
$Q_{boiler,STES}$	Boiler heat load (preheated STES) per day
$Q_{boiler,T<10}$	Boiler heat load per T<10°C per day
Q_{COMP}	Compressor load per day
Q_{COND}	Condenser heat load per day
$Q_{DH,delivered}$	Heat to be delivered in DH per day
$Q_{DH,losses}$	DH network losses per day
Q_{DHW}	Domestic Hot Water demand
$Q_{DHWdwelling}$	Energy demand per dwelling for Domestic Hot Water

$Q_{EL,HP}$	Electricity consumption by HP per day
$Q_{EL,PUMP}$	Electricity consumption by the pumps per day
Q_{EVA}	Evaporator heat load per day
$Q_{fromSTES}$	Heat load directly from STES per day
$Q_{GAS/BIO}$	Gas/Biomass consumption per day
Q_{H}	Heating demand
$Q_{Hdwelling}$	Energy demand per dwelling for Heating
Q_{solar}	Daily real solar production
Q_{SP}	Daily solar production
$Q_{STES\text{-}to\text{-}BOILER}$	Heat load from STES to Boiler per day
$Q_{STES\text{-}to\text{-}HP}$	Heat load from STES to HP per day
$Q_{STES,losses}$	STES heat losses per day
Q_{TOT}	Total Energy demand
$Q_{TOTdwelling}$	Total energy demand per dwelling
SC	Solar Collector
SCF	Solar Collector Field
SF	Solar Fraction
SF_{HP}	Solar Fraction with HP
SF_{noHP}	Solar Fraction without HP
STES	Seasonal Thermal Energy Storage
T_{amb}	Average daytime ambient temperature
$T_{amb,year}$	Average ambient temperature per year
T_{b}	Temperature required in the building
t_{b}	Bottom thickness
$T_{b,return}$	Building return temperature
TC_{HP}	Thermal Capacity o the HP
$T_{DH,return}$	DH return temperature per day
$T_{DH,supply}$	DH supply temperature per day
TES	Thermal Energy Storage
$T_{eva,max}$	Maximum Temperature in the Evaporator
T_{ground}	Ground temperature
T_{max}	Maximum Temperature in the STES
T_{min}	Initial Temperature in the STES
T_{out}	Output Temperature of HP
T_{STES}	STES temperature per day
TTES	Tank Thermal Energy Storage
t_{b}	Bottom thickness

t_{top}	Top thickness
t_{wall}	Wall thickness
U_{pipes}	Insulation DH Pipes
v	Fluid velocity in the pipes.
V_{aq}	Aquifer Volume
V_{STES}	STES Volume
α	Efficiency Factor of HP
ΔT	Temperature difference
ΔT_{HT}	Delta T in DH systems for HT costumer
ΔT_{LT}	Delta T in DH systems for LT costumer
η	Collector efficiency (η) per day
η_0	Solar Collector Optical efficiency
λ_b	Bottom Insulation conductivity
λ_{top}	Top Insulation conductivity
λ_{wall}	Wall Insulation conductivity
ρ	Water density
Φ	Latitude

1. INTRODUCTION

Deliverable 5.6 aims to describe the Decision Support Tool (DST) developed for the evaluation of a potential implementation of STES systems in existing buildings. DST investigates all the relevant technical issues to be considered for the STES system integration and gives an evaluation of the system from the energetic, environmental and economical point of view. The DST is designed to be a powerful and user-friendly calculation tool that allows Engineering and Construction companies without a specific expertise in these systems, to perform a preliminary design selecting the most suitable technology to install, according to the particular boundary conditions of the case under examination.

The innovative part of this tool is represented by the possibility of analyzing centralized as well as distributed configurations for the energy generation and distribution at building and district level. In both cases, solar plant and storage volume are centralized, but heat pumps and auxiliary boilers could be either centralized or distributed in buildings.

This report is divided in three main chapters. The first Chapter (# 2) describes the main characteristics of the Decision Support Tool.

In Chapter 3, the general architecture of the DST is described. The requested data as well as the results elaboration are reported.

In Chapter 4, the technical aspects related to the DST development are explained. It is a Web-based application available on line for free. Furthermore, the application logic is described and tool interfaces are provided.

In Chapter 5, future possible DST implementations are investigated.

Finally, Chapter 6 provides the conclusions of the performed work.

2. DST CHARACTERISTICS

Planning the integration of a solar thermal system with seasonal thermal energy storage requires a specific knowledge of the system and the location in which it will be installed. The influence of boundary conditions and system characteristics need to be investigated in order to perform a preliminary design of the system. In addition, having a transient system influenced by many quickly changing values, such as the solar energy availability, the heating demand of the customers and the temperatures inside the integrated system, a dynamic calculation is required to evaluate the interaction of all components. For these purposes, a Decision Support Tool (DST) has been developed. This tool is useful for selection, preliminary design and evaluation of overall integrated system in existing buildings composed by STES system, solar plants, heat pumps and auxiliary boilers. The DST is design to ensure that Engineers, without a specific knowledge of these systems, can be supported in the first phases of the system planning, giving a general overview of the entire process for the implementation of a STES system in existing buildings.

The Decision Support Tool is organized in three main sections: Input Data, Calculation and Results Section. In the first part the User is led through a series of well-defined steps aiming to collect the needed information and data to define the best fitting solution. In the Calculation section, the DST allows a dynamic analysis of the system, according to the inserted input data, with daily based energy balance. The integrated system is analysed from the energetic, environmental and economic point of view. Finally, the outputs of the DST are shown in the Results section. In order to make the DST user-friendly and accessible to different kind of Users, a specific Help has been developed and integrated into the DST to provide technical information related to the required data, the relative outputs as well as the default values used in the calculations. Detailed information about all the input data, the calculations performed by the DST and the outputs are explained in detail in the next chapter.

The aim of the Decision Support Tool is supporting the Users in the decision making process related to the identification of the most suitable technology to be implemented in a specific building, placed in a given location. The DST is able to evaluate the overall system performances considering different kinds of STES technologies. In order to select the most suitable one, some parameters are compared. They are summarized in the following points:

- Solar Fraction with the heat pump (SF_{HP}). It is the fraction of the heat demand covered by solar energy and heat pump.
- Primary Energy saving (PE_{saving}). It is the saving of primary energy achieved thanks to the installation of the overall system with respect to the primary energy consumed in the case of a traditional system
- CO_2 equivalent emission reduction indicator ($F_{CO2,eq}$). It is the reduction of CO_2 equivalent emission that the installation of STES system allows with respect to the same amount of energy produced with a traditional system.
- Total investment cost (CAPEX). It is the investment cost for all the components of the integrated system. It considers the main equipment costs, the costs for auxiliary equipment and the engineering indirect costs.
- Heat Cost (HC). It is the parameter used to quantify the cost of a specific system configuration.

The optimum technology is the one that enables to achieve the highest Solar Fraction and Primary Energy saving with the lowest Heat Cost.

3. DECISION SUPPORT TOOL DEVELOPMENT

The Decision Support Tool evaluates the performances of an integrated system composed by a STES system, a solar heating system, heat pumps and auxiliary boilers. Two different configurations have been considered based on two different distribution-generation strategies. In both cases, solar system and storage volume are centralized, but heat pumps and auxiliary boilers could be centralized or distributed in each building. The analysis is based on daily energy balances, allowing dynamic performance analysis of the systems. The tool is divided in three main sections: Input Data, Calculation and Results section.

3.1. INPUT DATA SECTION

In this section the data required by the Decision Support Tool are shown and explained. They can be categorized in seven main categories of data: General, District Heating, Heat Pump, Solar Collector, STES, Boiler and Economic Data. In order to make the tool user-friendly even for Users without a specific skill on this type of systems, the tool is able to provide a default value for almost all the required data. In case the User is not able to provide a data requested by DST, these default values can be used to complete the calculations..

3.1.1. General Data

In the general data section specifications about the distribution-strategy of the systems to be installed are required as well as the place where it is planned to be located and the heat demand that it has to cover.

Type of Configuration

The considered heat generation system is composed of a solar thermal system connected to a Seasonal Thermal Energy Storage (STES) tank, heat pumps and auxiliary boilers. This system is used for covering heat demands of consumers requiring Low Temperature (LT) or High Temperature (HT) heat. The User will choose one of two different configurations based on two different distribution-generation strategies. In both cases, solar system and storage tank are centralized, but heat pumps and auxiliary boilers could be installed at centralized or distributed level in each building.

DST will enable the User to select one of these two configurations for which a brief description is also provided:

- **Configuration A: Distributed generation**. Heat produced by the “Supply Side” is distributed to the buildings trough the DH network and auxiliary heat is locally provided, when needed, using boilers and heat pumps installed at building level (“Load side”).

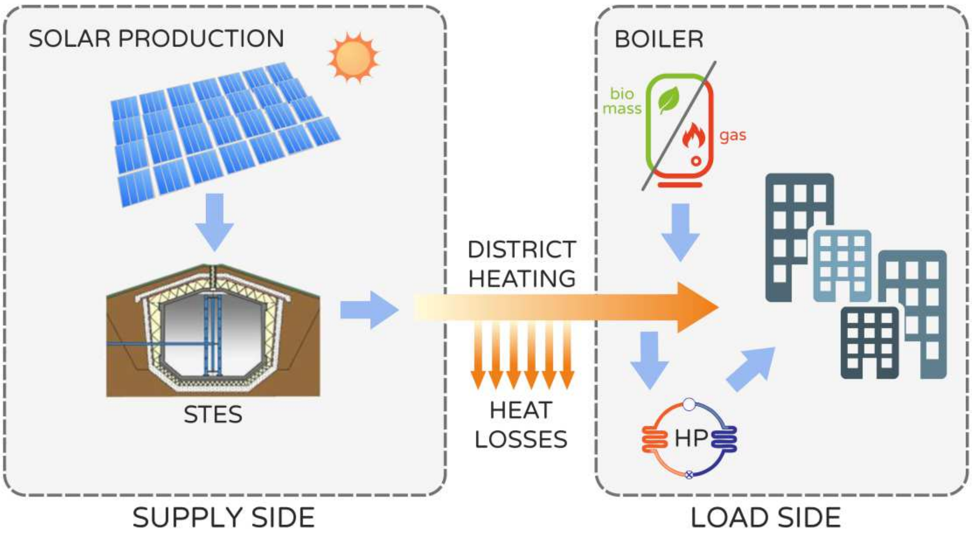


Figure 3.1. Configuration A scheme.

As control strategy for covering the heat demands, the following operation conditions have been established:

- The heat demand of High Temperature (HT) costumers will be always covered by decentralized boilers located at buildings level.
- When the temperature in the STES is higher than the temperature required by the Low Temperature (LT) costumers, heat will be delivered at this temperature. The Low temperature demand will be covered directly by the energy stored in the STES without the need f any auxiliary system.
- When the temperature in the STES is lower than the temperature required by the Low temperature costumers, heat will be delivered at the available temperature in the STES. The heat demand will be covered by heat pumps, using the District Heating network as low temperature source.
- When the temperature in the STES is lower than the minimum acceptable temperature to avoid freezing (10°C), the heat demand will be covered by decentralized boilers.

- **Configuration B: Centralized generation**. Boilers and heat pumps have a centralized production and are placed at seasonal storage tank level (“Supply Side”) in order to cover the heating gap for the water from the storage tank, when needed. After that, the water is distributed to the buildings (“Load Side”) trough the DH network.

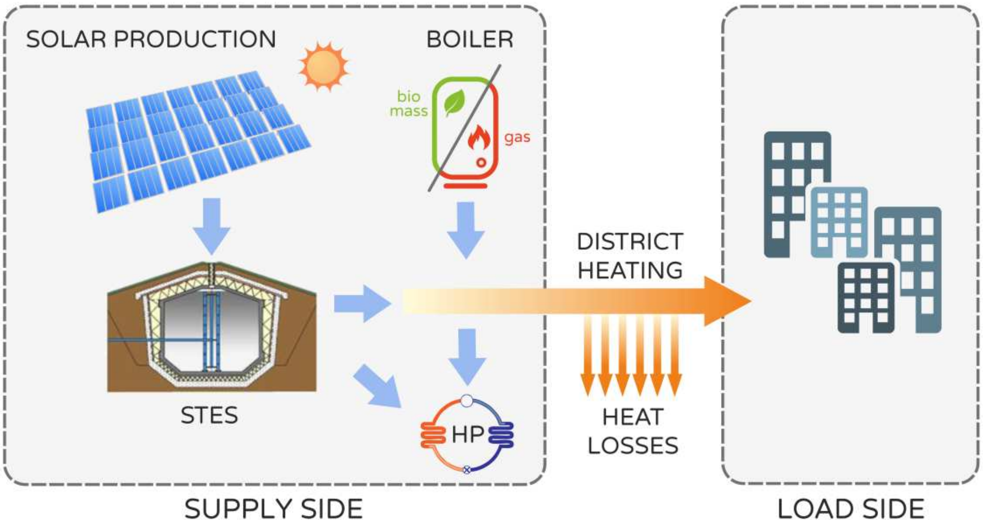


Figure 3.2. Configuration B scheme.

As control strategy for covering the heat demands, the following operation conditions have been implemented:

- When the temperature in the STES is higher than the temperature required by the High Temperature costumers, heat is delivered directly from the STES.
- When the temperature in the STES is lower than the temperature required by the LT costumers, auxiliary systems will be used. The heat demand could be covered by the heat pump, by the boiler or by both of them. The following strategy will be considered:
  - If the temperature in the STES is higher than acceptable temperature for the evaporator of the heat pump, the heat demand will be covered partly by the energy stored in the STES and partly by the boiler.
  - If the temperature in the STES is lower than acceptable temperature for the evaporator of the heat pump and higher than minimum acceptable temperature (10 °C), the heat demand will be covered partly by the heat pump and partly by the boiler. In this case the STES is used as low temperature source of the heat pump and the boiler is useful for increasing the temperature from the production temperature of the heat pump up to the required temperature by the costumers. If the heat pump is able to produce hot water at the required temperature by the costumers, the boiler would not have to operate.
- When the temperature in the STES is lower them the minimum acceptable temperature (10 °C), the heat demand is covered by boilers.

<u>Location</u>

The User has to select the place where the system should be installed. In order to allow a swift and user-friendly approach twenty-seven European cities are pre-loaded in the DST database and the User can select the one better representing the characteristics of the installation area. The selection of such cities has been made in order to cover different conditions for climatic and heating profiles at European level.

DST will enable the User to select the location from the following list of European cities:

Table 3.1. Location list.

Location		
Amsterdam	Helsinki	Riga
Athens	Lisbon	Rome
Berlin	Ljubljana	Sofia
Bratislava	London	Stockholm
Brussels	Madrid	Tallinn
Bucharest	Nicosia	Valletta
Budapest	Oslo	Vein
Copenhagen	Paris	Vilnius
Dublin	Prague	Warsaw

According to the selected location, DST will be able to identify the following parameters:

- Heating Degree Days (HDD_{15}). They are the sum, extended to all the days of an annual conventional period of heating, of the only positive differences between the conventional daily temperature (15 °C) and the average daily outside temperature. The HDD_{15} data are taken from the "Business Energy Efficiency (BizEE) Software": www.degreedays.net.
- Average daytime ambient temperature per month (T_{amb}) [°C]. Average temperature of the ambient in the time between sunrise and sunset per month.
- Total global irradiance G_T [W/m^2]. The power of the electromagnetic radiation from the sun per unit area incident on a surface. It is the sum of direct, diffuse and reflected component of the irradiance coming from the sun.
- Latitude (Φ) [°].. Geographic coordinate that specifies the north or south position of a particular location on the Earth's surface. It is the angle between the place considered and the Equator. Latitude ranges from 0° at the Equator to 90° (North or South) at the poles.
- Average ambient temperature per year ($T_{amb,year}$) [°C]. This data is useful for estimating the ground temperature (T_{ground}) considered constant and equal to $T_{amb,year}$ in case it will not be available.

  The average daytime ambient temperature per month, the total global irradiance, the latitude and the average ambient temperature per year values are taken from "Photovoltaic Geographical Information System (PV GIS) online platform": re.jrc.ec.europa.eu/pvgis/.

- Energy demand per dwelling for Heating ($Q_{Hdwelling}$) and Domestic Hot Water ($Q_{DHWdwelling}$). These data are used only if the User is not able to provide one of the following data:
  - Total Domestic Hot Water demand (Q_{DHW}). Amount of heat request for Domestic Hot Water preparation.
  - Total Heating demand (Q_H). Amount of heat request for space heating purpose.
  - Total Energy demand (Q_{TOT}). Sum of total Domestic Hot Water and Heating demand.

  These data are taken from the "European Environmental Agency (EEA) portal": www.eea.europa.eu

The obtained data are reported in the following tables.

Table 3.2. Heating Degree Days of the selected European cities [1].

Location \ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	HDD_{15}											
Amsterdam	306	256	221	117	86	33	7	29	22	74	249	292
Athens	132	119	111	49	7	0	0	0	0	13	48	177
Berlin	458	285	233	123	98	28	4	21	30	98	296	342
Bratislava	404	321	187	105	68	12	2	12	32	121	264	391
Brussels	293	251	217	116	94	40	12	30	35	79	274	296
Bucharest	482	376	191	117	40	4	0	1	28	137	211	471
Budapest	409	320	204	104	65	18	3	18	34	134	247	438
Copenhagen	426	335	301	203	108	27	4	20	37	93	271	324
Dublin	303	274	267	182	133	63	32	70	72	132	270	260
Helsinki	713	445	432	303	188	87	16	34	126	301	358	438
Lisbon	108	112	96	42	23	3	0	0	0	3	89	148
Ljubljana	362	359	254	135	90	29	11	18	56	128	289	453
London	264	225	206	121	79	22	7	29	25	68	240	260
Madrid	232	232	162	60	36	5	2	0	5	33	203	334
Nicosia	118	124	78	36	5	0	0	0	0	4	22	157
Oslo	617	429	386	286	177	68	14	65	131	248	446	467
Paris	272	230	193	108	78	25	8	15	25	62	256	293
Prague	464	358	267	159	130	48	14	40	58	158	337	439
Riga	653	414	355	250	141	66	10	32	99	273	322	408
Rome	196	131	158	71	33	3	0	0	1	30	124	223
Sofia	456	282	225	136	63	17	4	3	39	154	235	484
Stockholm	532	374	358	269	178	76	10	35	106	201	347	384
Tallinn	697	436	417	296	182	92	14	32	108	291	329	404
Valletta	58	56	73	18	5	0	0	0	0	0	18	62
Vein	410	323	199	116	76	17	2	10	33	121	277	385
Vilnius	688	445	325	217	118	69	14	44	99	276	334	455
Warsaw	569	389	276	171	90	38	5	29	62	193	297	410

Table 3.3. Average daytime ambient temperature per month [2].

Location \ Month	T_{amb} [°C] Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amsterdam	4	4,3	7,3	11,1	14	16,7	18,6	18,5	16,2	12,6	8,4	4,7
Athens	10,6	10,8	13	15,8	20	24,3	27,5	28	24,3	20,1	16,4	12,5
Berlin	0,9	1,9	5,4	11,2	15,7	18,6	20,7	20,2	16,2	11,5	6,5	1,8
Bratislava	0,5	2,4	6,9	13	17,7	20,7	22,9	22,5	17,5	12,4	7,1	1,4
Brussels	4,1	4,8	7,5	11,5	14,8	17,6	19,2	19,2	16,6	13,1	8,6	4,7
Bucharest	0	1,6	8,1	14,3	19,8	23,3	25,8	25,7	20,2	14,2	8,8	2,1
Budapest	0,3	1,9	7,3	13,7	18,6	21,7	23,7	23,7	18,2	13,2	7,4	1,3
Copenhagen	1,5	1,2	3,3	7,4	12	15,2	17,9	17,9	14,9	10,7	6,8	3
Dublin	6,8	7	7,8	9,6	11,7	14,3	16	16,1	15	12,3	9,2	7
Helsinki	-3	-4,9	-2	2,9	7,9	13,1	17,8	17,1	13,3	8,1	3,7	0,1
Lisbon	12	12,9	14,9	16,6	19,2	22,8	24,8	25,5	23,7	19,9	15,2	12,9
Ljubljana	1,7	3	7,9	13	17,6	21,1	23	22,5	17,5	13,2	8	2,8
London	5,8	6,1	8	10,9	13,8	16,7	18,5	18,5	16,4	13,2	9,1	6,1
Madrid	6,3	8	11,4	13,7	18,3	24,4	27,1	26,9	22,7	16,5	10,6	6,7
Nicosia	12,8	13,3	16,6	20,4	24,7	28,8	31,7	31,7	28,9	24,4	19,4	14,8
Oslo	-1,1	-1,2	2,8	7,1	12,3	15,1	17,6	17,7	13,8	8,7	4	-1,4
Paris	4,9	5,7	8,6	12,1	15,6	18,8	20,4	20,6	17,7	14,1	8,8	5,3
Prague	0,6	1,9	5,9	11,5	15,9	18,8	20,6	20,6	16	11,2	5,9	1,2
Riga	-3,4	-3,3	1	8,3	14	17	20,4	19	14,3	8,6	3,9	-1
Rome	9,7	9,9	12,8	15,8	20,4	24,3	27,1	27	22,6	19,4	15	11
Sofia	0,9	2	7,6	12,7	17,6	20,8	23,2	23,8	19	13,6	8,2	2,4
Stockholm	-1,9	-1,7	0,8	6,7	11,6	15,5	18,7	17,8	13,7	8,3	3,9	-0,3
Tallinn	-4,3	-5,3	-1,3	5,8	12,1	15,6	19,5	17,8	13,4	7,4	2,7	-2,6
Valletta	14,1	13,5	14,5	16,1	18,8	22,3	25,4	26	24,6	22,1	19,1	15,9
Vein	0,9	2,3	7	12,8	17,4	20,2	22,3	22,1	17,3	12,3	6,7	1,7
Vilnius	-4,3	-4,1	0,7	8,9	14,2	17	19,9	18,8	14	8,2	3,3	-2,1
Warsaw	-1,3	-0,2	4,2	11	15,9	18,7	21,2	20,6	15,6	10,5	5,8	0,2

Table 3.4. Total Global Irradiance for the selected European cities [2].

	G_T [W/m²]											
Month / Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Amsterdam	154,3	206,9	315,0	389,7	349,9	331,5	333,2	332,3	308,6	246,5	157,5	133,4
Athens	390,1	420,0	507,3	506,0	494,3	514,6	514,7	543,3	548,8	513,7	434,0	345,1
Berlin	128,7	199,4	316,1	382,8	350,9	344,2	336,0	341,1	324,0	251,7	154,1	112,8
Bratislava	167,1	255,2	365,2	425,4	393,4	371,3	390,9	411,4	371,3	309,1	184,7	139,0
Brussels	134,9	194,8	309,2	365,0	327,1	326,3	339,3	329,5	320,9	264,3	156,3	128,6
Bucharest	216,9	292,0	405,4	413,6	424,7	413,4	446,5	467,4	425,1	380,2	270,4	198,2
Budapest	168,8	251,9	357,1	396,4	377,8	366,3	382,6	407,9	357,1	333,6	208,0	137,6
Copenhagen	125,2	162,8	338,4	380,0	356,7	330,8	336,9	323,6	307,7	252,7	158,6	123,2
Dublin	177,4	242,6	332,1	349,5	352,7	322,0	304,9	306,1	308,0	245,9	218,5	174,1
Helsinki	86,0	220,2	258,9	323,6	321,9	292,9	307,2	265,3	215,6	138,3	69,5	51,9
Lisbon	381,8	457,3	489,6	472,0	466,5	473,4	495,4	535,0	527,6	487,9	412,5	364,3
Ljubljana	180,3	289,6	358,3	370,3	383,5	386,4	426,1	422,4	377,1	278,8	172,5	144,8
London	173,3	219,6	322,6	370,4	339,1	334,8	343,5	331,3	333,4	268,1	211,7	166,9
Madrid	395,1	468,8	504,1	469,4	449,3	481,7	534,8	562,9	543,5	497,9	409,8	402,0
Nicosia	442,1	469,7	538,9	501,1	481,3	503,9	533,7	559,4	578,9	584,2	541,0	458,7
Oslo	145,5	210,9	355,3	349,6	353,8	332,3	321,9	323,8	317,6	226,7	146,0	117,3
Paris	164,1	234,5	356,1	391,0	355,8	352,8	368,5	377,9	371,4	285,5	183,5	165,6
Prague	117,4	190,5	303,2	374,9	345,6	333,8	341,9	356,9	312,8	260,9	148,1	111,9
Riga	110,8	187,4	328,5	372,3	375,4	341,2	339,7	340,2	302,7	210,3	110,1	84,6
Rome	336,1	425,0	452,4	464,8	454,2	474,0	520,0	540,1	491,6	449,5	378,1	349,7
Sofia	222,4	266,6	337,4	360,4	354,5	375,2	422,2	454,8	391,1	360,4	294,9	216,0
Stockholm	138,3	204,1	366,1	379,8	377,2	351,7	336,0	341,2	317,8	220,7	145,1	117,0
Tallinn	110,5	171,9	302,3	366,2	359,5	331,4	328,3	322,0	273,9	181,7	96,8	77,3
Valletta	447,6	499,2	542,1	517,4	501,3	497,3	536,9	551,0	530,1	524,1	474,8	439,0
Vein	194,3	236,2	304,6	318,7	296,2	277,6	294,6	320,7	301,3	308,9	196,3	168,3
Vilnius	104,7	162,7	301,0	337,7	332,4	316,9	309,6	327,9	287,8	182,4	88,1	77,2
Warsaw	124,7	171,1	318,3	366,7	355,4	340,2	341,5	355,0	315,8	242,4	132,5	103,5

Table 3.5. Latitude and average ambient temperature per year of the selected European cities [2].

Location	Latitude (Φ) [°]	$T_{amb,year}$ [°C] = T_{ground} [°C]
Amsterdam	52	10,1
Athens	39	11,3
Berlin	51	9,4
Bratislava	48	4,8
Brussels	50	10
Bucharest	51	8,6
Budapest	47	11,1
Copenhagen	56	8,2
Dublin	53	10
Helsinki	61	4,2
Lisbon	39	15,9
Ljubljana	46	10,4
London	55	6,9
Madrid	40	14,3
Nicosia	35	20
Oslo	60	2,1
Paris	46	10,6
Prague	50	8,6
Riga	56	6,8
Rome	41	15,7
Sofia	43	7
Stockholm	60	6,3
Tallinn	58	6
Valletta	35	19,3
Vein	47	4,7
Vilnius	55	7,5
Warsaw	51	8,8

Table 3.6. Energy demand per dwelling for the selected European cities [3].

Location	$Q_{TOTdwelling}$ [MWh/year/dwelling]	$Q_{Hdwelling}$ [MWh/year/dwelling]	$Q_{DHWdwelling}$ [MWh/year/dwelling]
Amsterdam	14,15	11,69	2,46
Athens	11,79	10,79	1
Berlin	15,92	13,74	2,18
Bratislava	13,32	10,49	2,83
Brussels	19,24	16,64	2,6
Bucharest	8,1	6,44	1,66
Budapest	13,62	11,51	2,1
Copenhagen	16,46	13,92	2,54
Dublin	19,5	15,83	3,67
Helsinki	19,39	16,94	2,44
Lisbon	9,65	8,16	1,49
Ljubljana	13,54	10,63	2,91
London	14,25	11,22	3,03
Madrid	7,7	4,79	2,91
Nicosia	6,99	4,57	2,43
Oslo	21,86	18,49	3,38
Paris	14,27	12,43	1,84
Prague	15,13	12,49	2,63
Riga	17,32	15,1	2,23
Rome	10,55	9,38	1,17
Sofia	6,32	5,83	0,49
Stockholm	14,58	12,65	1,92
Tallinn	15,03	11,39	3,64
Valletta	7,33	6,2	1,13
Vein	17,77	15,46	2,3
Vilnius	9,61	8,72	0,9
Warsaw	11,79	9,97	1,82

Number of dwelling

The User has to select the number of dwellings associated to the energy demand to be covered. According to the European standards, the average size of dwellings is considered of 87 m^2 [4].

DST will enable the User to select a number of dwellings in a range from 5 to 200 with the following logic:

- If available → ok
- If not available → DST will assume as reference value $n_{dwelling}$ = 100 (assumption)

Domestic Hot Water Demand (Q_{DHW}) [MWh/year]

DST asks for the annual heat demand for Domestic Hot Water (DHW) preparation.

- If available → ok
- If not available → DST will calculate it with the following formula:

$$Q_{DHW}[MWh/y] = Q_{DHWdwelling} * n_{dwelling}$$

Being:

$Q_{DHWdwelling}$= Energy demand for Domestic Hot water per dwelling.

$n_{dwelling}$= number of dwelling.

Heating Demand (Q_H) [MWh/year]

DST asks for the annual heat demand for space Heating (H).

- If available → ok
- If not available → DST will calculate it with the following formula:

$$Q_H[MWh/y] = Q_{Hdwelling} * n_{dwelling}$$

Being:

$Q_{Hdwelling}$= Energy demand for heating per dwelling.

$n_{dwelling}$= number of dwelling.

Total Energy Demand (Q_{TOT}) [MWh/year]

DST needs the total heat demand per year. It is the sum of DHW and Heating demand.

- If available → ok (if available, DST will use always this value for Q_{TOT})
- If not available → DST will calculate Q_{TOT} with the following formula:

$$Q_{TOT}\ [MWh/y] = Q_{DHW} + Q_H$$

Being:

Q_{DHW}= Energy demand for Domestic Hot Water.

Q_H= Energy demand for heating.

Tilt Angle [°] of the solar collectors

Inclination angle of the solar panels. If there are no specific requirements due to the place where solar collectors will be installed, they need to be tilted at the correct angle to maximize the performance of the system. Maximum yearly solar radiation can be achieved using a tilt angle approximately equal to the site's latitude [5],[6].

DST approach for the selection of the Tilt Angle is the following:

- If available → ok, the User will select the tilt angle among the following values: 30°, 40°, 50°, 60°.
- If not available → DST will assume as default value the latitude of the location (Φ) [°] (see Table 3.5 in the LOCATION section).

The Tilt Angle is useful for evaluating the Daily Irradiation on a Tilted Surface (H) [kWh/(m^2day)] whose values are taken from "Photovoltaic Geographical Information System (PV GIS) online platform": re.jrc.ec.europa.eu/pvgis/.

DST will assume that the Daily Irradiation on a Tilted Surface (H) is constant in the "i" month. According to this assumption, H_i will be repeated equal every day of the "i" month.

For all the considered European cities, the Daily Irradiation on a surface tilted of 30°, 40°, 50°, 60° and tilted of an angle equal to the site latitude are shown in the following tables.

Table 3.7. Daily irradiation on a surface tilted of 30° [2].

	H(30°) [kWh/(m²day]											
Month / Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Amsterdam	1,15	1,86	3,48	5,15	5,40	5,48	5,33	4,75	3,74	2,46	1,26	0,92
Athens	3,46	4,19	5,89	6,49	6,95	7,56	7,53	7,28	6,66	5,38	4,06	3,05
Berlin	0,96	1,80	3,49	5,05	5,42	5,69	5,38	4,88	3,92	2,51	1,23	0,79
Bratislava	1,33	2,42	4,06	5,64	5,89	5,98	6,06	5,67	4,50	3,09	1,56	1,04
Brussels	1,12	1,84	3,46	4,93	5,15	5,39	5,34	4,73	3,92	2,64	1,35	1,01
Bucharest	1,85	2,92	4,71	5,51	6,18	6,47	6,74	6,49	5,17	3,99	2,42	1,59
Budapest	1,42	2,39	3,97	5,26	5,67	5,72	5,95	5,63	4,33	3,32	1,76	1,09
Copenhagen	0,90	1,54	3,72	5,27	5,69	5,88	5,69	4,88	4,01	2,43	1,02	0,65
Dublin	1,31	2,17	3,67	4,79	5,44	5,32	4,88	4,38	3,72	2,45	1,72	1,19
Helsinki	0,50	1,70	2,88	4,54	5,67	5,79	5,78	4,35	2,83	1,49	0,54	0,28
Lisbon	3,40	4,55	5,70	6,07	6,56	6,97	7,26	7,19	6,42	5,13	3,88	3,22
Ljubljana	1,53	2,73	4,15	4,93	5,73	6,02	6,37	5,83	4,54	2,94	1,55	1,16
London	1,29	2,07	3,57	4,90	5,24	5,54	5,49	4,74	4,03	2,67	1,68	1,15
Madrid	3,44	4,60	5,88	6,11	6,57	7,27	7,76	7,43	6,51	5,15	3,79	3,31
Nicosia	4,14	4,86	6,28	6,49	6,89	7,45	7,60	7,55	7,09	6,22	5,12	4,11
Oslo	0,85	1,75	3,85	4,91	5,94	6,12	5,60	4,91	3,79	2,11	0,99	0,57
Paris	1,31	2,23	3,95	5,19	5,33	5,69	5,73	5,23	4,50	2,86	1,56	1,23
Prague	1,05	1,87	3,45	4,96	5,21	5,47	5,31	4,92	3,83	2,52	1,26	0,92
Riga	0,77	1,67	3,60	5,08	5,95	5,98	5,76	5,01	3,65	1,99	0,82	0,51
Rome	2,97	4,21	5,25	5,95	6,61	7,20	7,60	7,23	5,97	4,71	3,36	2,91
Sofia	2,19	3,00	4,56	5,05	5,50	6,01	6,45	6,34	5,15	4,17	2,86	2,02
Stockholm	0,81	1,70	3,98	5,34	6,15	6,31	5,84	5,01	3,80	2,07	0,99	0,63
Tallinn	0,70	1,43	3,45	4,95	6,00	5,91	5,53	4,79	3,16	1,70	0,71	0,42
Valletta	4,19	4,99	6,32	6,67	7,09	7,35	7,63	7,44	6,47	5,53	4,47	3,90
Vein	1,35	2,49	4,01	5,51	5,68	5,73	5,81	5,45	4,32	2,98	1,55	1,14
Vilnius	0,74	1,47	3,34	4,65	5,31	5,43	5,13	4,70	3,49	1,83	0,71	0,51
Warsaw	0,93	1,55	3,52	4,84	5,49	5,63	5,47	5,06	3,81	2,42	1,06	0,72

Table 3.8. Daily irradiation on a surface tilted of 40° [2].

Month / Location	H(40°) [kWh/(m²day)]											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Amsterdam	1,26	1,98	3,60	5,17	5,26	5,28	5,16	4,70	3,81	2,59	1,36	1,02
Athens	3,72	4,39	5,98	6,35	6,58	7,02	7,04	7,02	6,69	5,60	4,35	3,30
Berlin	1,04	1,91	3,61	5,08	5,28	5,49	5,20	4,83	4,01	2,65	1,32	0,86
Bratislava	1,42	2,55	4,17	5,62	5,71	5,72	5,84	5,60	4,58	3,24	1,66	1,11
Brussels	1,21	1,95	3,56	4,93	5,01	5,18	5,15	4,67	3,99	2,77	1,45	1,11
Bucharest	1,97	3,08	4,83	5,45	5,93	6,12	6,42	6,35	5,24	4,19	2,59	1,71
Budapest	1,52	2,51	4,07	5,23	5,48	5,47	5,72	5,55	4,39	3,49	1,88	1,17
Copenhagen	1,00	1,65	3,92	5,34	5,59	5,69	5,55	4,87	4,15	2,60	1,12	0,72
Dublin	1,45	2,33	3,80	4,81	5,31	5,13	4,72	4,33	3,81	2,59	1,90	1,34
Helsinki	0,57	1,90	3,05	4,63	5,60	5,64	5,67	4,36	2,92	1,60	0,60	0,32
Lisbon	3,65	4,80	5,78	5,94	6,23	6,49	6,80	6,94	6,46	5,34	4,16	3,51
Ljubljana	1,63	2,88	4,25	4,88	5,54	5,74	6,11	5,72	4,61	3,05	1,63	1,23
London	1,41	2,20	3,68	4,90	5,10	5,33	5,31	4,68	4,12	2,81	1,83	1,28
Madrid	3,73	4,88	6,00	6,00	6,26	6,80	7,29	7,21	6,58	5,39	4,09	3,62
Nicosia	4,43	5,08	6,34	6,31	6,45	6,85	7,05	7,21	7,06	6,45	5,47	4,44
Oslo	0,97	1,94	4,13	5,03	5,88	5,98	5,49	4,94	3,97	2,30	1,12	0,67
Paris	1,40	2,34	4,06	5,17	5,16	5,44	5,51	5,15	4,59	2,99	1,65	1,34
Prague	1,12	1,97	3,54	4,95	5,06	5,24	5,12	4,86	3,89	2,63	1,34	0,99
Riga	0,85	1,80	3,79	5,15	5,86	5,79	5,61	5,01	3,76	2,12	0,89	0,56
Rome	3,23	4,48	5,36	5,87	6,31	6,76	7,18	7,04	6,04	4,93	3,63	3,20
Sofia	2,34	3,13	4,64	4,97	5,27	5,68	6,13	6,18	5,20	4,37	3,07	2,17
Stockholm	0,92	1,87	4,25	5,46	6,09	6,15	5,73	5,04	3,97	2,24	1,12	0,72
Tallinn	0,78	1,56	3,66	5,05	5,93	5,76	5,41	4,81	3,27	1,82	0,78	0,48
Valletta	4,51	5,23	6,39	6,48	6,66	6,76	7,07	7,11	6,46	5,72	4,77	4,22
Vein	1,44	2,64	4,12	5,50	5,50	5,49	5,59	5,37	4,39	3,12	1,65	1,23
Vilnius	0,79	1,55	3,46	4,67	5,19	5,23	4,97	4,66	3,57	1,92	0,75	0,54
Warsaw	1,00	1,63	3,64	4,86	5,36	5,43	5,30	5,02	3,90	2,54	1,13	0,78

Table 3.9. Daily irradiation on a surface tilted of 50° [2].

	H(50°) [kWh/(m²day]											
Month / Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amsterdam	1,34	2,05	3,64	5,07	5,01	4,96	4,88	4,55	3,80	2,66	1,42	1,09
Athens	3,88	4,47	5,92	6,06	6,06	6,32	6,38	6,58	6,54	5,66	4,52	3,46
Berlin	1,10	1,97	3,65	4,99	5,03	5,16	4,93	4,68	4,00	2,72	1,39	0,91
Bratislava	1,48	2,63	4,19	5,48	5,40	5,34	5,48	5,39	4,55	3,31	1,73	1,16
Brussels	1,27	2,00	3,58	4,82	4,76	4,86	4,87	4,50	3,97	2,84	1,52	1,18
Bucharest	2,05	3,16	4,83	5,26	5,55	5,65	5,95	6,05	5,19	4,29	2,70	1,79
Budapest	1,59	2,58	4,08	5,08	5,18	5,10	5,36	5,33	4,35	3,57	1,96	1,22
Copenhagen	1,07	1,73	4,02	5,29	5,36	5,39	5,28	4,74	4,19	2,71	1,19	0,78
Dublin	1,56	2,43	3,85	4,72	5,07	4,84	4,47	4,19	3,81	2,67	2,03	1,46
Helsinki	0,61	2,04	3,15	4,61	5,41	5,37	5,44	4,27	2,96	1,67	0,63	0,35
Lisbon	3,82	4,92	5,73	5,67	5,76	5,86	6,18	6,51	6,32	5,41	4,33	3,70
Ljubljana	1,69	2,96	4,26	4,73	5,22	5,34	5,71	5,48	4,57	3,09	1,68	1,28
London	1,53	2,30	3,69	4,71	4,68	4,81	4,84	4,41	4,07	2,91	1,97	1,40
Madrid	3,93	5,03	5,98	5,75	5,80	6,18	6,65	6,80	6,47	5,49	4,28	3,84
Nicosia	4,60	5,16	6,24	5,98	5,88	6,08	6,31	6,70	6,85	6,50	5,68	4,65
Oslo	1,07	2,07	4,29	5,01	5,69	5,71	5,27	4,87	4,06	2,43	1,23	0,74
Paris	1,46	2,41	4,08	5,03	4,89	5,08	5,18	4,95	4,57	3,05	1,71	1,41
Prague	1,17	2,02	3,56	4,83	4,80	4,92	4,83	4,69	3,86	2,69	1,39	1,03
Riga	0,90	1,89	3,89	5,10	5,63	5,49	5,35	4,89	3,79	2,19	0,95	0,60
Rome	3,40	4,63	5,35	5,65	5,88	6,17	6,59	6,67	5,95	5,02	3,80	3,40
Sofia	2,43	3,19	4,61	4,78	4,93	5,22	5,67	5,87	5,12	4,45	3,20	2,27
Stockholm	1,01	1,99	4,42	5,45	5,89	5,86	5,49	4,95	4,05	2,35	1,21	0,80
Tallinn	0,85	1,64	3,79	5,02	5,73	5,49	5,18	4,72	3,31	1,90	0,84	0,52
Valletta	4,70	5,34	6,31	6,14	6,07	6,03	6,34	6,60	6,28	5,77	4,95	4,44
Vein	1,50	2,72	4,14	5,36	5,21	5,13	5,26	5,17	4,36	3,19	1,71	1,29
Vilnius	0,83	1,60	3,51	4,59	4,96	4,94	4,71	4,53	3,57	1,96	0,78	0,57
Warsaw	1,05	1,67	3,67	4,76	5,10	5,11	5,01	4,87	3,89	2,61	1,18	0,82

Table 3.10. Daily irradiation on a surface tilted of 60° [2].

	H(60°) [kWh/(m2day)]											
Month / Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amsterdam	1,38	2,07	3,59	4,85	4,65	4,55	4,50	4,30	3,70	2,67	1,46	1,14
Athens	3,93	4,44	5,71	5,61	5,39	5,47	5,56	5,96	6,22	5,58	4,57	3,53
Berlin	1,13	1,99	3,61	4,77	4,68	4,74	4,55	4,42	3,91	2,73	1,42	0,94
Bratislava	1,51	2,64	4,11	5,20	4,97	4,85	5,01	5,05	4,41	3,31	1,75	1,19
Brussels	1,30	2,02	3,51	4,60	4,41	4,45	4,48	4,24	3,86	2,84	1,55	1,22
Bucharest	2,09	3,16	4,71	4,95	5,05	5,05	5,35	5,61	5,00	4,28	2,75	1,82
Budapest	1,61	2,59	3,99	4,82	4,76	4,63	4,89	4,99	4,21	3,56	2,00	1,24
Copenhagen	1,12	1,76	4,02	5,11	5,01	4,97	4,90	4,51	4,13	2,75	1,24	0,82
Dublin	1,63	2,48	3,80	4,52	4,72	4,44	4,13	3,96	3,72	2,68	2,11	1,53
Helsinki	0,65	2,13	3,17	4,48	5,11	5,00	5,09	4,08	2,92	1,70	0,66	0,37
Lisbon	3,88	4,91	5,53	5,26	5,15	5,11	5,42	5,92	6,02	5,34	4,39	3,79
Ljubljana	1,71	2,97	4,16	4,47	4,78	4,82	5,18	5,11	4,41	3,06	1,68	1,29
London	1,55	2,31	3,65	4,58	4,49	4,59	4,63	4,26	4,00	2,90	1,99	1,43
Madrid	4,03	5,05	5,81	5,36	5,21	5,42	5,85	6,21	6,19	5,45	4,36	3,96
Nicosia	4,66	5,11	5,98	5,49	5,17	5,19	5,43	6,01	6,46	6,38	5,73	4,74
Oslo	1,14	2,16	4,35	4,88	5,37	5,31	4,93	4,67	4,05	2,50	1,30	0,80
Paris	1,49	2,41	4,00	4,77	4,51	4,63	4,74	4,64	4,43	3,04	1,73	1,44
Prague	1,19	2,02	3,49	4,60	4,44	4,50	4,44	4,40	3,75	2,68	1,41	1,06
Riga	0,94	1,94	3,89	4,93	5,28	5,07	4,97	4,66	3,74	2,22	0,98	0,62
Rome	3,48	4,65	5,20	5,28	5,30	5,44	5,84	6,13	5,71	4,98	3,87	3,51
Sofia	2,47	3,18	4,48	4,48	4,48	4,66	5,08	5,41	4,92	4,42	3,25	2,31
Stockholm	1,07	2,07	4,48	5,31	5,55	5,45	5,14	4,75	4,02	2,41	1,28	0,86
Tallinn	0,90	1,69	3,82	4,88	5,40	5,09	4,84	4,52	3,27	1,94	0,87	0,55
Valletta	4,77	5,30	6,06	5,64	5,34	5,15	5,47	5,93	5,93	5,66	4,99	4,54
Vein	1,53	2,73	4,07	5,09	4,80	4,66	4,80	4,85	4,22	3,18	1,73	1,32
Vilnius	0,85	1,61	3,48	4,40	4,62	4,54	4,36	4,29	3,49	1,96	0,78	0,58
Warsaw	1,08	1,68	3,62	4,56	4,74	4,69	4,63	4,60	3,79	2,62	1,19	0,84

Table 3.11. Daily irradiation on a surface tilted of an angle equal to the city latitude [2].

	H(Φ) [kWh/(m²day]											
Month / Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Amsterdam	1,35	2,06	3,64	5,04	4,95	4,89	4,81	4,51	3,79	2,67	1,43	1,10
Athens	3,70	4,37	5,97	6,37	6,63	7,08	7,10	7,05	6,69	5,58	4,32	3,28
Berlin	1,10	1,97	3,65	4,97	5,00	5,12	4,89	4,65	4,00	2,72	1,39	0,91
Bratislava	1,47	2,62	4,19	5,52	5,47	5,42	5,56	5,44	4,56	3,30	1,72	1,16
Brussels	1,27	2,00	3,58	4,82	4,76	4,86	4,87	4,50	3,97	2,84	1,52	1,18
Bucharest	2,06	3,16	4,82	5,24	5,51	5,59	5,90	6,01	5,17	4,30	2,71	1,79
Budapest	1,57	2,57	4,08	5,14	5,28	5,22	5,48	5,41	4,37	3,55	1,94	1,21
Copenhagen	1,11	1,75	4,03	5,19	5,16	5,15	5,07	4,62	4,17	2,74	1,22	0,81
Dublin	1,58	2,45	3,84	4,67	4,97	4,73	4,38	4,13	3,79	2,68	2,06	1,48
Helsinki	0,65	2,14	3,17	4,46	5,07	4,95	5,05	4,06	2,91	1,70	0,66	0,37
Lisbon	3,63	4,78	5,78	5,96	6,27	6,54	6,86	6,97	6,46	5,32	4,14	3,48
Ljubljana	1,67	2,94	4,27	4,80	5,36	5,51	5,88	5,60	4,60	3,08	1,66	1,26
London	1,53	2,30	3,69	4,71	4,68	4,81	4,84	4,41	4,07	2,91	1,97	1,40
Madrid	3,73	4,88	6,00	6,00	6,26	6,80	7,29	7,21	6,58	5,39	4,09	3,62
Nicosia	4,30	4,99	6,33	6,42	6,69	7,17	7,35	7,40	7,10	6,36	5,31	4,29
Oslo	1,14	2,16	4,35	4,88	5,37	5,31	4,93	4,67	4,05	2,50	1,30	0,80
Paris	1,44	2,39	4,08	5,10	5,01	5,24	5,32	5,05	4,59	3,04	1,69	1,38
Prague	1,17	2,02	3,56	4,83	4,80	4,92	4,83	4,69	3,86	2,69	1,39	1,03
Riga	0,92	1,92	3,90	5,01	5,43	5,25	5,14	4,77	3,77	2,22	0,97	0,62
Rome	3,25	4,50	5,37	5,86	6,28	6,71	7,13	7,01	6,04	4,94	3,65	3,22
Sofia	2,38	3,16	4,64	4,93	5,18	5,55	6,00	6,10	5,19	4,40	3,12	2,20
Stockholm	1,07	2,07	4,48	5,31	5,55	5,45	5,14	4,75	4,02	2,41	1,28	0,86
Tallinn	0,89	1,68	3,82	4,92	5,48	5,18	4,91	4,56	3,28	1,93	0,87	0,55
Valletta	4,36	5,13	6,38	6,60	6,89	7,08	7,38	7,30	6,49	5,64	4,64	4,07
Vein	1,49	2,70	4,15	5,41	5,31	5,25	5,37	5,25	4,38	3,18	1,69	1,27
Vilnius	0,84	1,61	3,51	4,51	4,80	4,75	4,55	4,42	3,54	1,96	0,78	0,57
Warsaw	1,06	1,67	3,67	4,75	5,07	5,07	4,98	4,85	3,89	2,61	1,18	0,82

Percentage of Demand at High and Low Temperature (HT%, LT%) [%]

The integrated system can cover the heat demand of different types of customers. Some of them can demand Low Temperature (LT) heat and others can claim High Temperature (HT) heat. The User have to indicate the percentage of the heat demand requested at LT and the complementary one at HT. DST approach to collect this information is reported below:

- If available → ok
- If not available → DST will assume as default values:
  - HT% = 10%.
  - LT% = 90%.

The identified percentages are then applied to the energy demand (Q_{TOT}) to implement the calculation.

3.1.2. Heating Network Data

In the Heating Network data section specifications about the heating distribution systems are required. There are two different distribution systems: one at district heating level for the heating distribution from the integrated system to the buildings and one at building level for the heat received from the integrated system and delivered to the customers. The operational temperatures of the heating systems in buildings as well as the main characteristics of the district heating network have been considered because they affect the efficiency of the solar thermal and the district heating systems.

District Heating (DH) Presence

The User has to indicate if a network is already present at district level. DST logic associated to this data is reported below:

- If yes → ok.
- If no→ all the data connected to the District Heating are not necessary.

Type of Heating Technologies

The User has to indicate the Heating technology used at building level. The heating system within the buildings influences the required temperatures in the DH network and consequently the overall efficiency of the system. DST considers the following possibilities:

- If available → ok, the User will select the technology among: Air heating, Floor heating, Medium temperature radiators, High temperature radiators (conventional), Underfloor heating.
- If not available → DST will assume as default system High temperature radiators (conventional).

This information is useful for selecting the following data:

- Temperature required in the building (Tb) [°C] - DST will assume the relative value according to the following table including the typical delivery temperatures for various heating distribution system (EINSTEIN D3.2 – Ulster).

Table 3.12. Typical delivery temperatures for various heating distribution system [7].

Heating systems	Heating Technologies	Temperature range [°C]	Typical building temperature T_b [°C]
Air distribution	Air heating	30-50	40
	Floor heating	30-45	40
Hydronic systems	Medium temperature radiators	45-55	50
	High temperature radiators (conventional)	60-90	80
	Underfloor heating	30-35	35

- Delta T in DH systems (ΔT_{LT}, ΔT_{HT}) – These values are useful in order to determine the return temperatures from the buildings and from the District heating network. DST will assume the relative value according to the following table. In case of Configuration B, being a centralized system delivering only heat at the temperature required by the HT costumers, DST will assume $\Delta T_{LT} = \Delta T_{HT}$

Table 3.13. Delta T in DH systems for each heating technologies.

Heating systems	Heating Technologies	ΔT_{LT} [°C]	ΔT_{HT} [°C]
Air distribution	Air heating	10	15
	Floor heating	10	15
Hydronic systems	Medium temperature radiators	15	20
	High temperature radiators (conventional)	20	30
	Underfloor heating	5	10

DH Network size

The User has to select the size of District Heating Network already present or to be implemented. He can choose between Small or Big DH size. This information is needed to identify a reasonable value for the 'DH Network Distance' with aim to not overestimate or underestimate the district losses.

DH Network distance (L) [m]

The User has to indicate the district heating network extension. This value is important in order to quantify the DH heat losses. DST establish a value for this data using the following criteria:

- If available → ok.
- If not available → DST will assume as default value L=10000 [m] in case of Big DH Network and L=1000 [m] in case of Small DH Network.

DH Pipe Internal Diameter (D_{pipes}) [m]

The User has to indicate the Internal Diameter of the DH, if already present. DST logic to determine this data is reported below:

- If available → ok.
- If not available → DST will calculate D_{pipes} with the following formula (further details are reported in the "Calculation Section").

$$D_{pipes}[m] = \sqrt{\frac{4 * \dot{m}_{DH,max}}{\pi * v * \rho}}$$

Insulation DH Pipes (U_{pipes}) [W/mK]

The User has to indicate the DH linear thermal transmittance if it is already present. It is the rate of heat transferred through a length unit (1 m) of insulation material divided by the temperature difference between the two sides of it. This value is important in order to quantify the DH heat losses The following principles are put in practice by the DST to identify this data:

- If available → ok.
- If not available → DST will consider as default value U_{pipes} = 0,25 W/mK [8].
- If not available but D_{pipes} is available → DST will consider the U_{pipes} value according to the following table

Table 3.14. Suggested values of insulation thermal transmittance of DH pipes by diameter.

Diameter (m)	U (W/mK)	Diameter (m)	U (W/mK)
0,05	0,206	0,55	1,082
0,1	0,294	0,6	1,169
0,15	0,381	0,65	1,257
0,2	0,469	0,7	1,344
0,25	0,556	0,75	1,432
0,3	0,644	0,8	1,519
0,35	0,732	0,85	1,607
0,4	0,819	0,9	1,694
0,45	0,907	0,95	1,782
0,5	0,994	1	1,870

DH Pump Hydraulic Heat (H_{pump}) [mwc]

The User has to indicate the hydraulic Heat of the DH pumps. It represents the driving force for water flows in the DH pipes and it is defined as the pressure difference between the starting and arriving point of the DH network. This value is important in order to calculate the electricity consumption of the DH pump. DST concept to collect this data is the following:

- If available → ok.
- If not available → DST will assume as default value H_{pump}= 30,6 [mwc] [9].

DH Pump Electrical Efficiency ($P_{EL,eff}$) [-]

The User has to indicate the Electrical efficiency of the DH pump. It is defined as the ratio between the existing power from and the power entering into the DH pump. This value is important in order to calculate the electricity consumption of the DH pump and DST approaches as reported below to identify a value:

- If available → ok.
- If not available → DST will assume as default value $P_{EL,eff}$ = 0.6 [-] [10].

Ground Temperature (T_{ground}) [°C]

The User has to indicate the soil temperature, useful for calculating the heat losses of the district heating network. The following strategy is applied by the DST to have this data:

- If available → ok
- If not available → DST will assume as default value the average ambient temperature per year ($T_{amb,year}$) [11] (see Table 3.5 in the LOCATION section). It is a good approximation on yearly base because for a period of the year the heat losses are overestimated and for the rest are underestimated therefore on annual basis the final result is balanced.

3.1.3. **Solar Collector Data**

In the Solar Collector (SC) data section specifications about the solar thermal system are required. The type of solar collector to be installed and the area covered by them mainly influence the solar production and the solar system efficiency. For this reason, the User has to specify them into the DST.

Types of Solar Collector (SC)

The User has to indicate the SC that will be installed, if available, choosing within a list of three main solar collectors types. The selection should be made considering the available space and the required temperatures. At general level, if the available space is limited and/or in case of high temperature application, it is recommended to select high efficiency collectors.

Regarding solar collectors, DST follows the selection principles reported below:

- If available → ok, the User will select one of the following options:
  - High performing Flat Plate Collector (FPC_h).
  - Medium performing Flat Plate Collector (FPC_m).
  - High performing Evacuated Tube Collector (ETC).

- If not available → DST will consider the following criteria based on the required temperatures:
  - If $T_b \leq 50°C$ (low operating temperature) – DST will use as default solar collector type FPC_h
  - If $T_b > 50°C$ (high operating temperature) - DST will use as default solar collector type ETC

For each SC typology, the DST has to calculate the efficiency influenced by typical parameters that are different according to the various SC types. DST will use representative collector parameter values for the selected collector type as reported in the table below.

Table 3.15. Solar collectors parameters [12].

Collector Type	η_0 [-]	k_1 [W/Km^2]	k_2 [W/K^2 m^2]
	Optical efficiency	1st order heat loss coefficient	2nd order heat loss coefficient
FPCh	0,80	3,0	0,008
FPCm	0,75	4,0	0,010
ETC	0,75	1,0	0,005

Specific Solar Collector Area (c_1) [m^2/(MWh/y)]

The User has to indicate the proportionality coefficient for a preliminary design of the solar collector field. DST logic for the identification of the Specific Solar Collector Area is reported below:

- If available → ok.
- If not available → DST will assume as default value c_1=1.9 [m^2/(MWh/y)]. It is the medium value of the following range: 1.4 – 2.4 [m^2/(MWh/y)] [13]. These values are indicated in literature as suitable proportionality coefficients for a preliminary design of the solar collector field in a Central Solar District Heating system with Seasonal Storage.

Solar Collector Area (A_{SC}) [m^2]

The User has to indicate the area size where the solar collectors will be installed. Higher is the SC area and higher is the solar production. For that reason, all the available space suitable for the solar collector installation should be used. DST logic for the identification of the Solar Collector Area is reported below:

- If available → ok
- If not available → DST will assume as default value an area calculated using the following formula:

$$A_{SC}[m^2] = Q_{TOT}[MWh/y] * c_1 \ [\frac{m^2}{MWh/y}]$$

Being:

Q_{TOT} = Total Energy demand per year.

c_1= Specific Solar Collector Area

3.1.4. STES system Data

In the STES system data section specifications about the Seasonal Storage are required. The characteristics of the soil and of the storage are mainly investigated in order to evaluate the most suitable STES typology.

Aquifer Presence

The User has to indicate if an aquifer is present in the site where the system will be installed. It is useful in order to evaluate the possibility to install an Aquifer Thermal Energy Storage system. DST logic related to the aquifer presence is reported below:

- If yes → The User has to specify the following values:
  - Aquifer Volume (V_{aq})[m^3]
  - Permeability (k_f) [m/s]

    DST will consider ATES technology only if [5]:

    $V_{aq} \geq 100.000$ m3

    $k_f > 10^{-5}$ m/s
- If no → DST will not consider ATES technology

Type of Soil

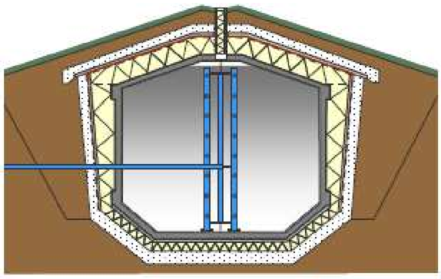
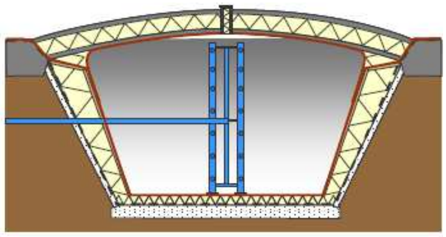
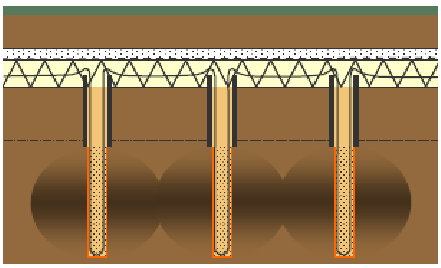
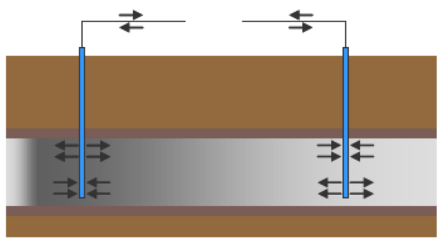
The soil typology must be investigated in order to evaluate which storage systems are suitable. The User is able to select one of the following options:

- Rock → DST will consider all STES systems
- Water saturated soil → DST will consider all STES systems
- Other → DST will consider all STES systems apart from BTES

STES typology selection

DST will select the type of STES system applicable to the specific case starting from the typologies reported in the following table according to the results coming from the previous two points “Aquifer presence” and “Type of soil”. In addition to that DST will show a brief summary of the characteristic of each STES typology.

Table 3.16. Seasonal Thermal Energy Storage typologies.

Tank thermal energy storage (TTES)	
• Suitable geological conditions: tank construction can be built almost independently from geological conditions, as much as possible avoiding groundwater • Depth: from 5 to 15 m • Heat storage capacity: between 60 and 80 kWh/m^3 • Maximum temperature in the STES: 90°C • Tank's characteristics: **Structure** made of concrete, stainless steel or fiber reinforced polymer. A coating of polymer or stainless steel covers the inside tank surface. The outside surface has an **insulation layer** of foam glass gravel for the bottom part, and expanded glass granules in membrane sheeting for walls and top.	
Pit thermal energy storage (PTES)	
• Suitable geological conditions: almost independent from geological conditions, as much as possible avoiding groundwater • Depth: from 5 to 15 m • Heat storage capacity with gravel-water mixture: between 30 and 50 kWh/m^3 (equivalent to 0.5-0.77 m^3 of water) • Maximum temperature in the STES: 80°C • Pit thermal energy storage filled with water or gravel-water mixture (gravel fraction 60-70%)	
Borehole thermal energy storage (BTES)	
• Suitable geological formations: rock or water saturated soils with no or only very low natural groundwater flow. The ground should have high thermal capacity and permeability. • Depth: from 30 to 100 m • Heat storage capacity of the ground: between 15 and 30 kWh/m^3 • Maximum temperature in the STES: 60°C • Heat directly stored in the water-saturated soil: u-pipes, also called ducts, are inserted into vertical boreholes to build a huge heat exchanger.	
Aquifer thermal energy storage (ATES)	
• Suitable geological formations: aquifer with high porosity, ground water and high hydraulic conductivity (kf > 10^{-5} m/s), small flow rate, up and down enclosed with leak-proof layers. • Heat storage capacity: between 30 and 40 kWh/m^3 • Maximum temperature in the STES: 50°C • Aquifers defined as naturally occurring self-contained layers of ground water, are used for heat storage.	

Specific STES Volume (c_2) [m^3/m^2]

The User has to indicate the proportionality coefficient for a preliminary design of the storage volume. DST logic for the identification of the Specific STES Volume is reported below:

- If available → ok.
- If not available → DST will assume as default value c_2= 1.75 [m^3/m^2]. It is the medium value of the following range: 1.4 - 2.1 m^3/m^2 [13]. These values are indicated in literature as suitable proportionality coefficients for a preliminary design of the storage volume in a Central Solar District Heating system with Seasonal Storage.

STES Volume (V_{STES}) [m^3]

The User has to indicate the volume available for the storage system installation. With the same storage volume, the different STES typology will have different performances due to the different storage capacities. DST consider the following criteria for the STES volume identification:

- If available → ok
- If not available → DST will assume as default value a volume calculated using the following formula:

$$V_{STES}[m^3] = A_{SC}\ [m^2] * c_2\ [m^3/m^2]$$

Being:

A_{SC}= solar collector area

c_2 = Specific STES Volume

Especially for urban installation, STES should be designed in such a way that the space covered by the STES can be used also for other purposes, such as playground for children, parking lots, etc.

Initial Temperature in the STES (T_{min}) [°C]

The User has to indicate the temperature in STES at the beginning of the system operation phase. DST logic for the identification of this data is reported below:

- If available → ok
- If not available → DST will assume as default value the minimum acceptable temperature in the STES to avoid freezing. T_{min} = 10°C [5].

Maximum Temperature in the STES (T_{max}) [°C]

The User has to indicate the maximum temperature achievable in the STES system. DST follows the criteria reported below in order to collect this data:

- If available → ok
- If not available → DST will assume as default value the data reported in the table below.

Table 3.17. Maximum Temperature in the STES.

STES Typology	T_{max} [°C]
TTES	90
PTES	80
BTES	60
ATES	50

H/D ratio (c_3)

The User has to indicate the ratio between the height and the diameter of a cylinder associated to the STES volume (V_{STES}). The H//D ratio identification approach foreseen for the DST is the following:

- If available → ok
- If not available → DST will assume c_3 = 1 [14]. This is the best value for the H/D ratio in order to reduce thermal losses.

Insulation conductivity (λ) [W/mK]

The User has to indicate, if available, the insulation conductivity related to the insulation layer of top (λ_{top}), bottom (λ_b)and wall (λ_{wall}) parts of STES. DST follows the values identification criteria reported below:

- If available → The user provides λ_{top}, λ_b and λ_{wall}
- If not available → DST will assume the values reported in the table below:

Table 3.18. Insulation conductivity of each layer per each STES technology.

	Insulation conductivity λ	
Technology / Layers	**TTES**	**PTES**
Top	PUR granules λ_{top} = 0,036 W/(mK)	Expended glass granules λ_{top} = 0,06-0,08 W/(mK)
Bottom	Foam Glass Gravel FGG λ_b = 0,08-0,10 W/(mK)	
Wall	Expended Glass Granules EGG λ_{wall} = 0,06-0,08 W/(mK)	

DST performs the calculations considering TTES for all cases changing only the data associated to the different type of insulation. In addition, for BTES and ATES technologies the default values for insulation data are considered the same of TTES.

Top thickness (t_{top}) [m]

The User has to specify, the thickness of the storage top. DST considers the following criteria for identifying a value for the top thickness:

- If available → ok
- If not available → DST will assume as default value t_{top} = 0,3 [m].

Bottom thickness (t_b) [m]

The User has to specify, the thickness of the storage bottom. The logic for the identification of a value for this data is reported below:

- If available → ok
- If not available → DST will assume as default value t_b = 0,4 [m]

Wall thickness (t_{wall}) [m]

The User has to specify, if available, the thickness of the storage wall. DST considers the following logic for a value identification:

- If available → okIf not available → DST will assume as default value t_{wall} = 0,55 [m]

3.1.5. Heat Pump Data

In the Heat Pump data section specifications about the Heat Pump are required. By using the HP, the temperature levels and the system overall efficiency can be optimized.

Heat Pump Presence

The User has to indicate if Heat Pumps will be installed in the system. DST logic associated to the HP presence is reported below:

- If yes → ok
- If no→ all the data connected to the District Heating are not necessary

Maximum Temperature in the Evaporator ($T_{eva,max}$) (°C)

The User has to indicate the maximum temperature achievable in the evaporator. DST approach for identifying this data is reported below:

- If available → ok
- If not available → DST will assume as default value $T_{eva,max}$ = 55°C [15].

Efficiency Factor of HP (α) [-]

The User has to indicate the efficiency factor of the HP used for the evaluation of its Coefficient of Performance (COP). Below is reported the strategy adopted by the DST for identifying a value to be associated to this data:

- If available → ok
- If not available → DST will assume as default value α = 0,5 [15].

Output Temperature of HP (T_{out}) [°C]

The User has to indicate the temperature of water coming out from the heat pump. DST considers the following criteria for its definition:

- If available → ok
- If not available → DST will assume the following default values T_{out} = 75 [°C].

Thermal Capacity o the HP (TC_{HP}) [kW_{th}]

The User has to indicate the HP thermal capacity useful to calculate the investment cost for this component. DTS considers the following possibilities:

- If available → ok
- If not available → DST will assume default value TC_{HP} = 90 kW_{th}

3.1.6. Boiler Data

In the Boiler data section the characteristic of the auxiliary boilers are specified, with particular reference to the used energy source and the boilers efficiency.

Type of energy source

The typology of boiler to be installed must be indicated; within DST, User can select one of the following types of sources:

- GAS
- BIOMASS
- GAS and BIOMASS; in case the User selects GAS+BIOMASS, DST will ask to specify the PERCENTAGE OF GAS AND BIOMASS in USE, following the criteria reported below:
    - If available → ok
    - If not available → DST will assume the following default values:
        - GAS% = 60 [%]
        - BIO% = 40 [%]

Boiler efficiency (B_{eff}) [-]

DST asks of specifying the boiler efficiency according to the chosen energy source. If "GAS and BIOMASS" energy source is considered, DST will ask for the efficiencies of both boiler sources, according to the following criteria:

- If available → ok
- If not available → DST will assume a default value according to the energy source, as reported in the following table

Table 3.19. Boiler efficiency for each type of energy source [16].

Type of energy source	B_{eff} [-]
GAS ($B_{eff,GAS}$)	0,85
BIOMASS ($B_{eff,BIO}$)	0,75

3.1.7. Economic Data

In the economic data section information related to components and energy sources costs are specified. This data are fundamental in order to evaluate the energy cost for the installation of these types of systems.

Solar Collector Specific Cost (c_{sc}) [€/m²]

The User has to indicate the cost per solar collectors surface unit in order to evaluate their total investment cost. DST applies the following rules for the determination of this parameter:

- If available → ok, DST will calculate the total solar collector cost C_{SC} [€] with the following formula:

$$C_{SC}[€] = c_{SC} * A_{SC}$$

  Being:

  A_{SC}= solar collector area.

- If not available → DST will calculate the total solar collector cost C_{SC} [€] with the following from literature [5][17]:

$$C_{SC}[€] = \gamma * 740 * A_{SC}^{0,860}$$

  Being:

  A_{SC}= solar collector area

  γ is a parameter used to consider the economic behaviour of different solar collector typologies. DST will assume for γ the values reported in the table below:

Table 3.20. Coefficient for economic behavior of the different SC typologies [18].

Solar collectors	γ
FPCm	1
FPCh	1,5
ETC	2

STES Specific Cost (c_{STES}) [€/m³]

The User has to indicate the cost per volume unit of the STES in order to evaluate the total investment cost associated to the STES implementation.

- If available → ok, DST will calculate the total STES cost C_{STES} [€] with the following formula:

$$C_{STES}[€] = c_{STES} * V_{STES}$$

Being:

V_{STES}=Seasonal storage volume

- If not available → DST will calculate the total STES cost C_{STES} [€] with the following formula from literature [5],[17]:

$$C_{STES}[€] = \beta * 4660 * V_{STES}^{0,615}$$

Being:

V_{STES}= Seasonal storage volume.

β is a parameter used to consider the economic behaviour of different technologies of thermal energy storage. DST will assume for β the values reported in the table below:

Table 3.21. Coefficient for economic behavior of the different STES technology [19].

	β
TTES	1
PTES	1/2
BTES/ATES	1/3

Heat Pump (HP) Specific Cost (c_{HP}) [€/KW$_{th}$]

The User has to indicate the cost per unit thermal capacity of the HP in order to evaluate the total investment cost for it.

- If available → ok, DST will calculate the total heat pump cost (C_{HP}) [€] with the following formula:

$$C_{HP}[€] = c_{HP} \; * TC_{HP}$$

With:
TC_{HP} = Thermal Capacity of the Heat Pump [kW$_{th}$]

- If not available → DST will calculate the total heat pump cost (C_{HP}) [€] with the following formula:

$$C_{HP}[€] = -0{,}0396 * TC_{HP} + 144{,}81 * TC_{HP} + 2174{,}8$$

With:

TC_{HP} = Thermal Capacity of the Heat Pump [kW$_{th}$].

Gas Cost (C_{GAS}) [€/MWh]

The User has to indicate the gas cost in order to evaluate the total operational costs of the integrated system.

- If available → ok
- If not available → Depending on the site of installation of the system, DST will consider the values in the following table [20]:

Table 3.22. Gas cost per city.

Location	C_{GAS} [€/MWh]
Amsterdam	85
Athens	89
Berlin	69
Bratislava	52
Brussels	67
Bucharest	31
Budapest	42
Copenhagen	111
Dublin	72
Helsinki [21]	33
Lisbon	93
Ljubljana	66
London	59
Madrid	89
Nicosia [21]	76
Oslo [21]	95
Paris	73
Prague	58
Riga	50
Rome	95
Sofia	52
Stockholm	122
Tallinn	48
Valletta [21]	69
Vein	75
Vilnius	61
Warsaw	51

Biomass Cost (C_{BIO}) [€/MWh]

The User has to indicate the cost of the biomass in order to evaluate the total operational costs.

- If available → ok
- If not available → Depending on the site of installation of the system, DST will consider the values in the following table:

Table 3.23. Biomass cost per city [21].

Location	C_{BIO} [€/MWh]
Amsterdam	38
Athens	40
Berlin	55
Bratislava	30
Brussels	38
Bucharest	29
Budapest	36
Copenhagen	58
Dublin	58
Helsinki	26
Lisbon	33
Ljubljana	32
London	36
Madrid	26
Nicosia	48
Oslo	66
Paris	38
Prague	38
Riga	41
Rome	48
Sofia	40
Stockholm	26
Tallinn	41
Valletta	48
Vein	52
Vilnius	41
Warsaw	31

Electricity cost (C_{EL}) [€/MWh]

The User has to indicate the cost of the electricity in order to evaluate the total operational costs.

- If available → ok
- If not available → Depending on the site of installation of the system, DST will consider the values in the following table:

Table 3.24. Electricity cost per city [20]

Location	C_{EL} [€/MWh]
Amsterdam	192
Athens	170
Berlin	292
Bratislava	168
Brussels	222
Bucharest	128
Budapest	133
Copenhagen	294
Dublin	241
Helsinki	156
Lisbon	213
Ljubljana	166
London	180
Madrid	208
Nicosia	248
Oslo	178
Paris	159
Prague	149
Riga	136
Rome	232
Sofia	88
Stockholm	205
Tallinn	137
Valletta	170
Vein	202
Vilnius	139
Warsaw	144

3.2. CALCULATION SECTION

In this paragraph the architecture of the calculation section of the DST is presented. It is divided in three main parts:

- Energy Demand
- System Energy Model
- Energy Consumption

In the first part, the monthly and daily loads of the heat demand are calculated in order to allow an energy balance of the integrated system with a low time step. The integrated system behaviour and the energy flows are evaluated in the second part. Finally, the consumptions of energy source and electricity are calculated.

3.2.1. Energy Demand

In this section of the DST the heat load for space heating, domestic hot water preparation and for their sum are calculate on monthly and daily base. Thanks to this calculation, in the "System Energy Model" section an energy balance of the system will be done with a daily time step.

3.2.2. System Energy Model

In this section of the DST an energy balance of the integrated system is performed with a daily time step. The solar production, the accumulate energy in the STES, the heat losses from seasonal storage and district heating, the boiler and heat pump heat load are evaluated in order to analyse the system behaviour.

A schematic representation of the energy flows considered by the DST is shown in the following figures.

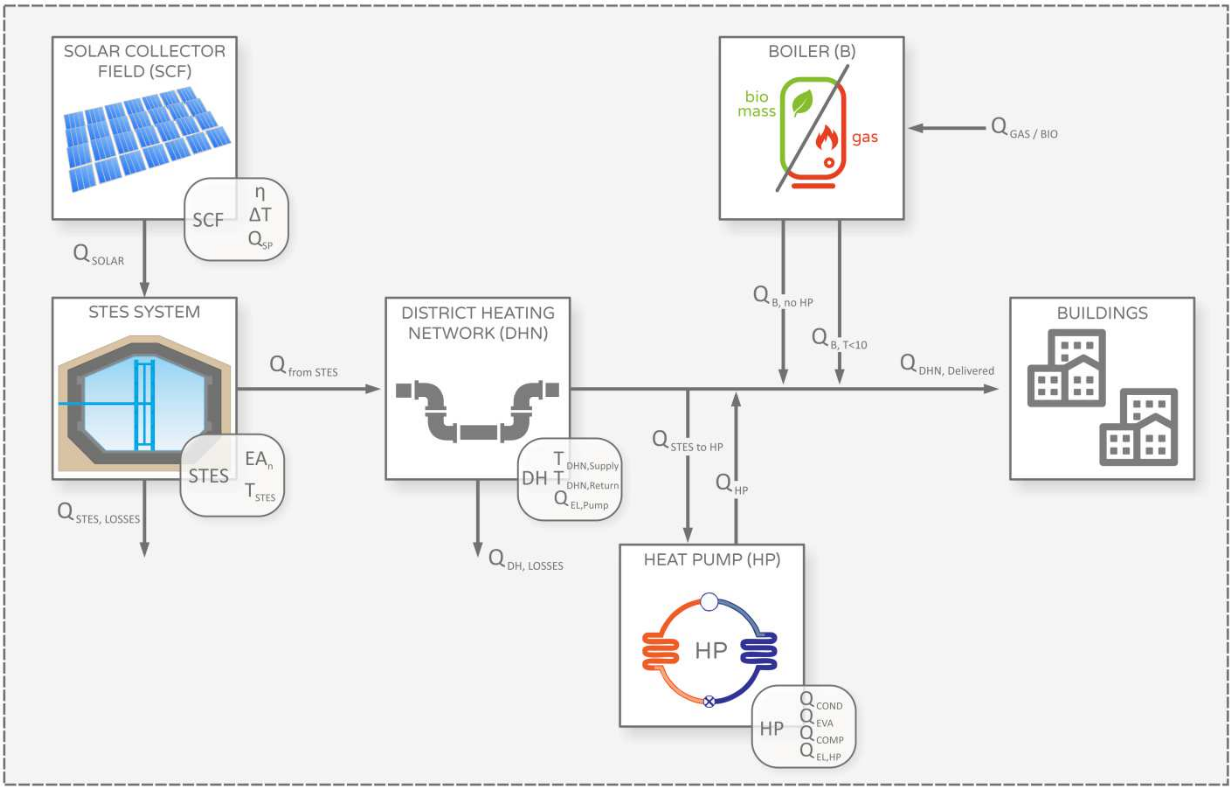


Figure 3.3 Distributed Configuration.

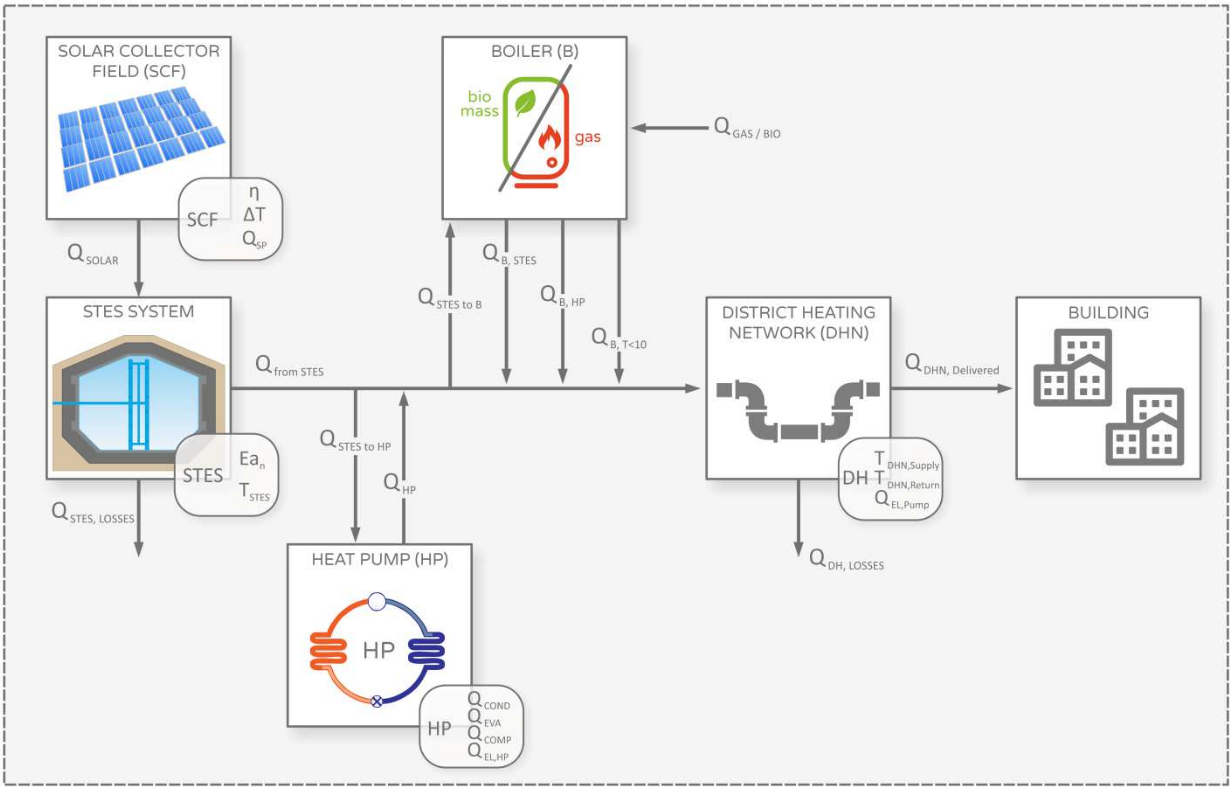


Figure 3.4 Centralized Configuration.

<u>Solar Collector Field</u> (SCF)

The solar production entering in the STES is calculated in this section considering the collectors efficiency and the thermal losses in the solar field pipes.

<u>District Heating Network</u> (DHN)

In this part of calculation section, an analysis at DH network level is performed. The temperatures in the network at building and district level are evaluated and a district energy balance is performed. In particular, the heat losses from the district heating network and the heat to be delivered at district level to cover the energy demand are calculated day by day.

<u>Heat Pump</u> (HP)

In this section the HP operation is analysed. Energy performances and heat flows are calculated.

<u>STES system</u> (STES)

In this part of calculation section the energy balance of the STES is performed.

<u>Boiler</u> (B)

According to the strategy of the operation of the different system configurations, the heat demand covered by the boiler is calculated in this part of calculation section.

3.2.3. Energy Consumption

In this part of calculation section the energy sources and electricity consumptions are calculated. These data are useful for the subsequent analysis of the system performances.

3.3. DST RESULTS

The heat loads, the temperatures and the energy performances of the system are evaluated on monthly and yearly base in this section. They are useful for giving to the User a monthly trend of the system parameters and heat loads as well as to give some information about the applicability of this kind of systems in a particular location. In addition, a brief environmental and economical analysis is performed. The first step is the evaluation of the environmental advantages coming from the use of these kinds of system. The second part is the study of the system costs. At the end of the calculation, the energy cost reached thanks to the implementation of this integrated system is calculated.

3.3.1. Energy Performances

In this part of calculation section the trend of the system parameters and heat loads are evaluated on monthly base. They are useful in order to evaluate the performances of the systems. In particular the percentages of the heat demand covered by the main component of the system, the efficiencies of the solar plant and STES system are calculated. At the end of these calculations, the DST calculates the primary energy saving achieved thanks to the installation of such integrated system.

3.3.2. Environmental Performances

In this section the amount of greenhouse gas emissions caused by the energy use is calculated for the integrated and traditional systems. It is calculated applying a conversion factor at the energy consumptions.

3.3.3. Economic Analysis

In this section an economic analysis of the system is performed; the main equipment investment costs, the operational and maintenance costs as well as the annual costs are evaluated in order to estimate the heat cost with this kind of system. This indicator could be considered in order to select the best system configuration.

4. DEFINITION OF DECISION SUPPORT TOOL ARCHITECTURE

The Decision Support Tool described before has been developed as a Web-based application and it is currently available on-line at the following link:

http://einstein.dappolonia-innovation.com/einstein-dst/login.jsf

Once the validation process will be in a more advanced stage, a link for having direct access to the DST will be included in the first page of the EINSTEIN project website (http://www.einstein-project.eu/)

In this Chapter, the Technical aspects related to the DST are explained in detail.

4.1. TECHNICAL ASPECTS

4.1.1. General Architecture

The DST is implemented as web-based application. It is an application program that is stored on a remote server and delivered at the Internet through a browser interface. All the parts of the software are downloaded from the web each time it is running. With a computer connected to the Internet and a web browser, the Users can have easily access to the DST from any location. This option is useful to monitor the usage of the Tool and to facilitate the update process. By updating the application on the server, all users have access to the update version. A web-based application allows also that high computational resources are not required to the client device.

The figure below details a three-layer web application model. The first layer is the user interface; the second one is the dynamic content generation technology tool and the third layer is the database containing content and customer data.

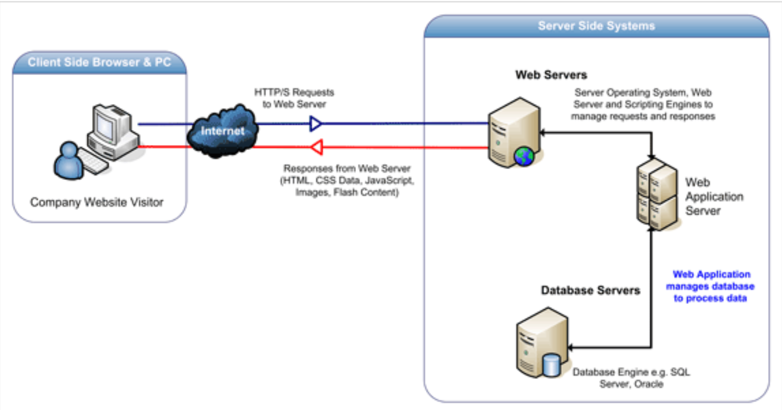


Figure 4.1. Three-layer web application model.

As Web-based application, the Decision Support Tool does not require a specific hardware configuration for the User machine that access the tool: the main requirement is the availability of an internet connection. EINSTEIN DST is designed to work with the current or immediately previous version of the most commonly used browsers such as Mozilla Firefox, Chrome Microsoft Internet Explorer or Safari.

4.1.2. Application Logics

The approach for the implementation of the DST user interface is based on the "Wizard" concept: basically, the user interface shows a sequence of dialog boxes that lead the user through a series of well-defined steps aiming to collect the needed information and data to define the solution that will be suggested at the end. For each requested data DST specifies if it is optional or not. The dialog boxes are:

1. *Introduction*: A brief description of the Decision Support Tool functionality is included in this part of the tool.

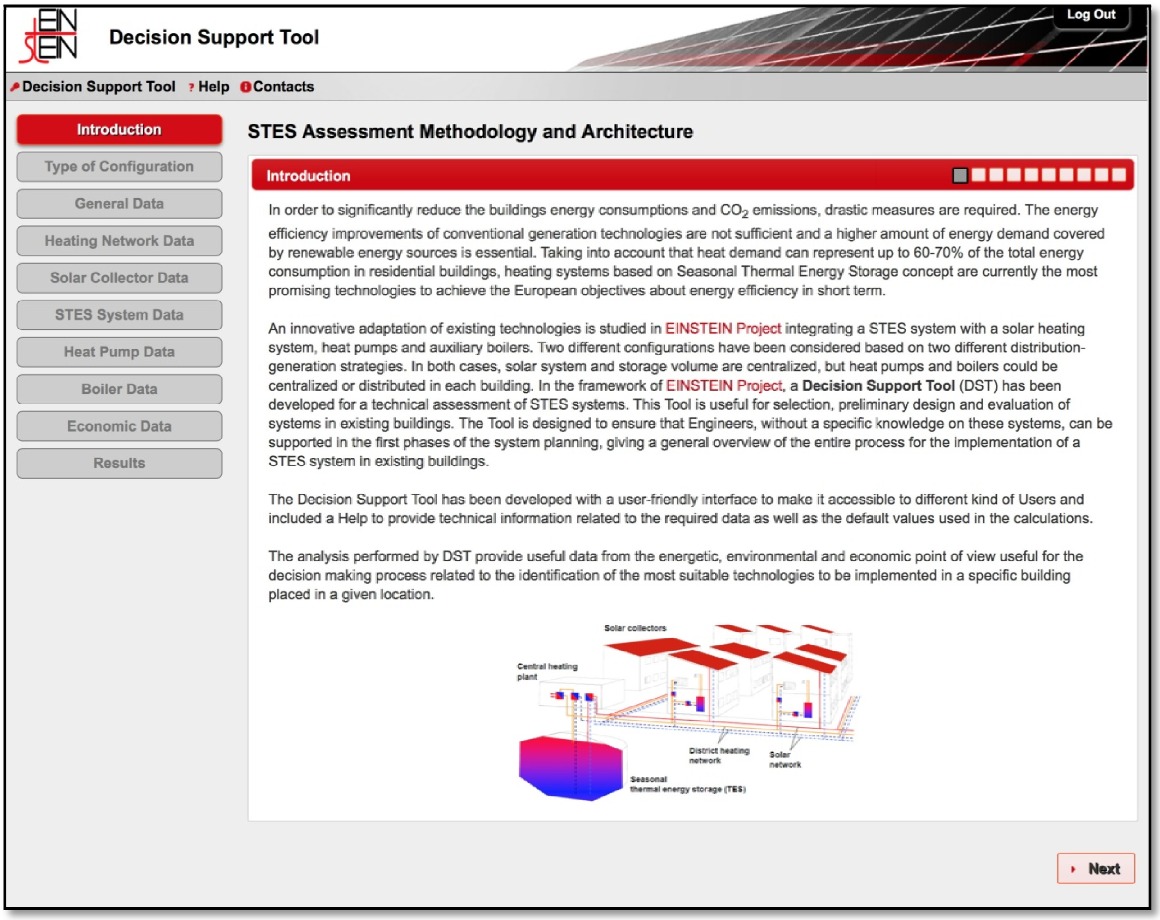


Figure 4.2. Introduction dialog box.

2. *Type of Configuration*: The User has to choose a type of configuration between Centralized and Decentralized one. A brief description of these two configurations and a figure that outline them is provided. The User is obliged to select one configuration, otherwise an error box appears underlining that this step is mandatory for allowing the calculations.

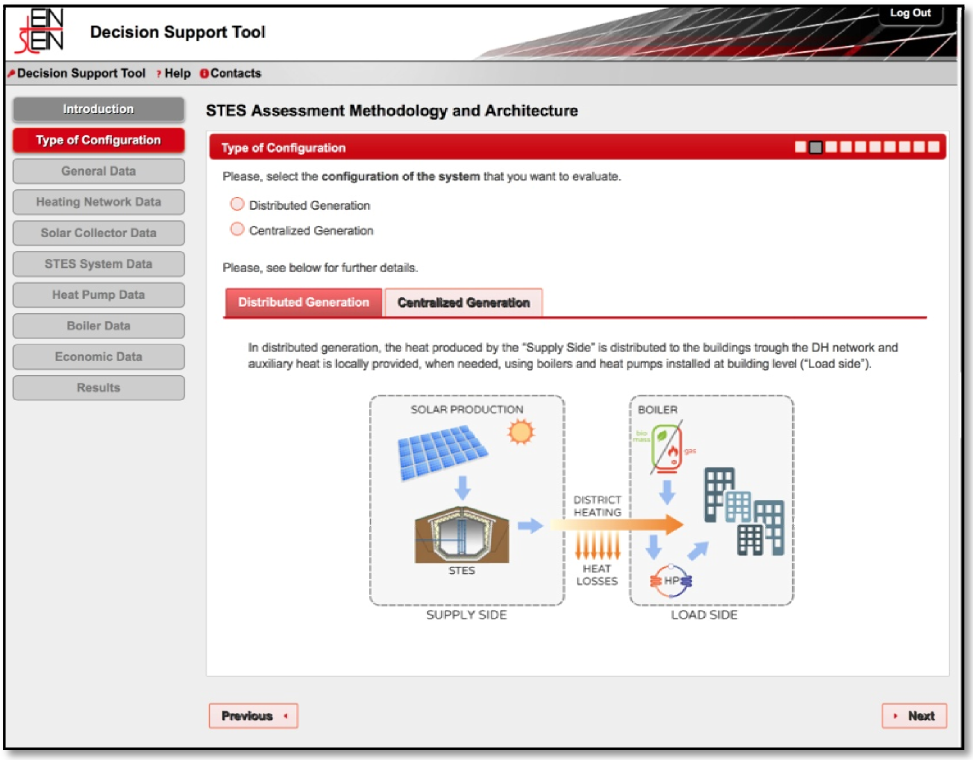


Figure 4.3. Type of Configuration dialog box.

3. *General Data*: In this dialog box the User has to specified the location in which the system will be installed and the required energy demand. Additional information about the required data is also included in the same box for providing to the Users details useful for having a clear idea about the inputs at the basis of the analysis. These details are identified by the symbol of a light bulb.

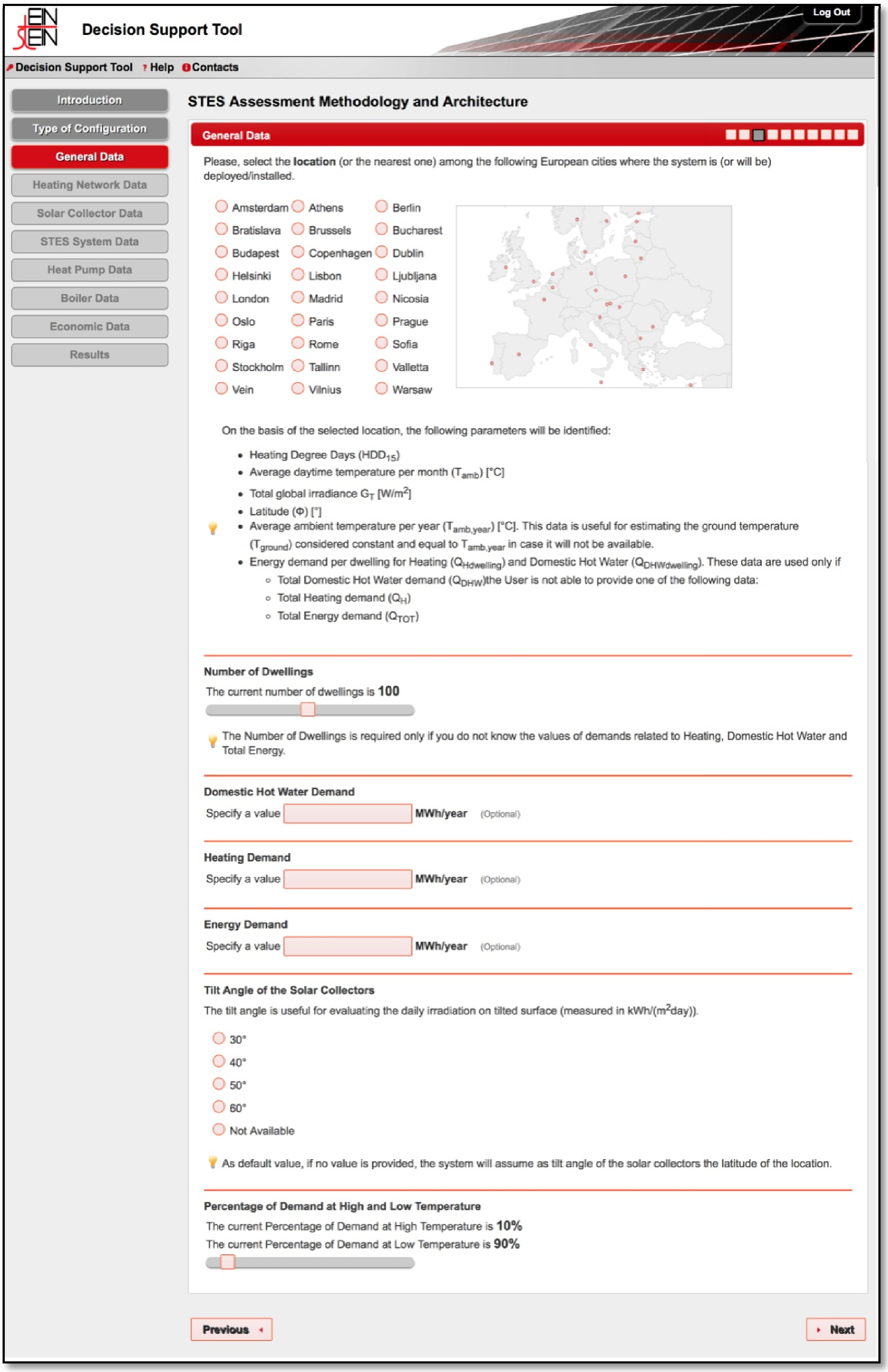


Figure 4.4. General Data dialog box.

4. *Heading Network Data*: Information about the typology of the heating technology installed in the buildings and about the possible district heating network is required in this dialog box.

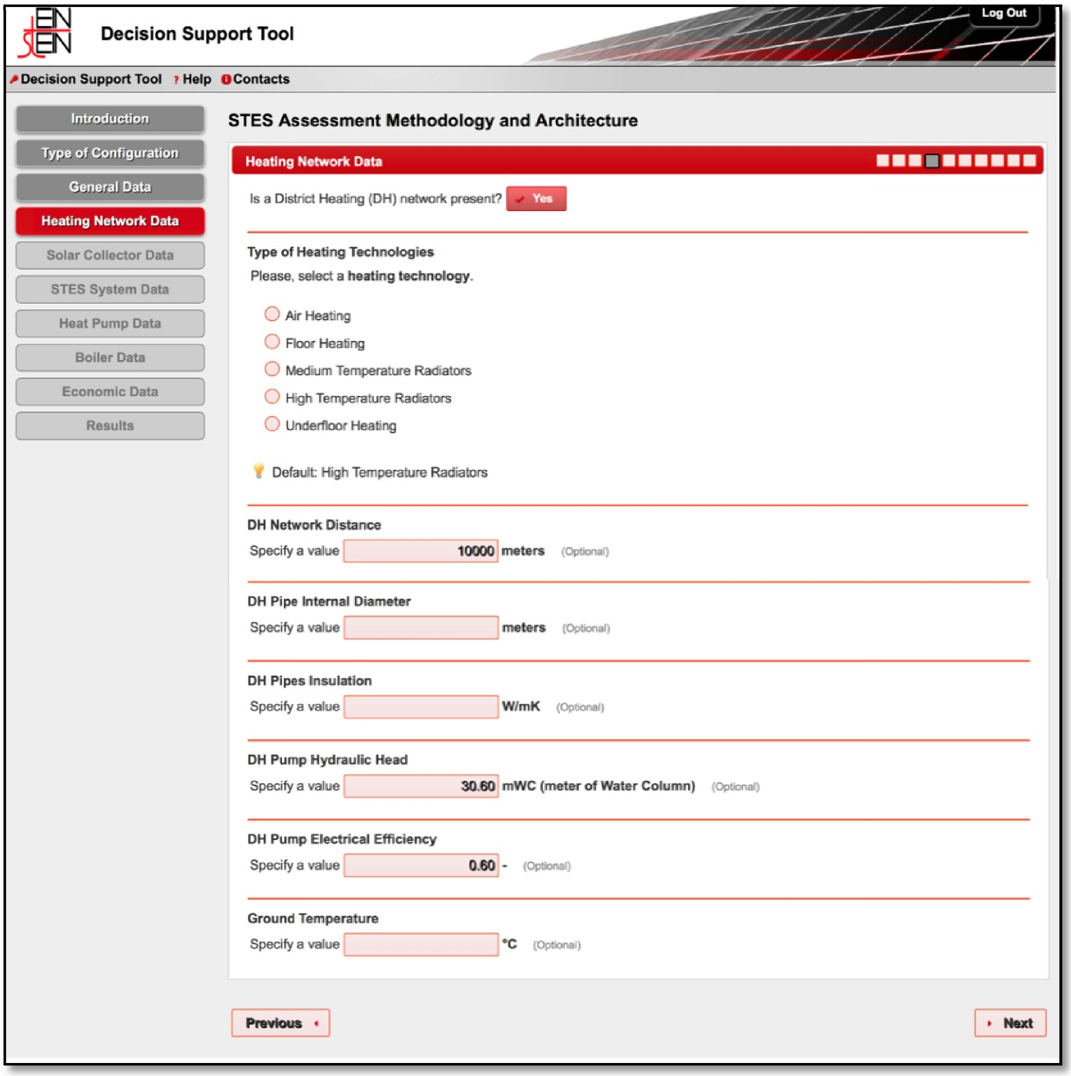


Figure 4.5. Heating Network Data dialog box.

5. *Solar Collectors Data*: The type of solar collectors and the size of the area where they will be installed are asked in this dialog box. This information is optional.

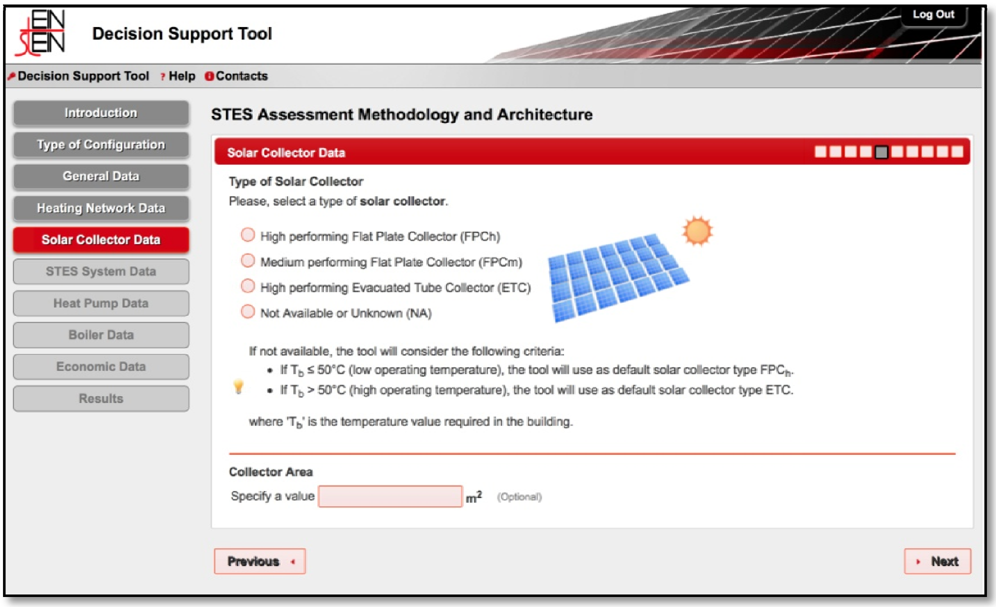


Figure 4.6. Solar Collectors Data dialog box.

6. *STES system Data*: In this dialog box information about the STES system is required. First, a brief description of the four typology of STES considered by the DST is provided. After that, information about the characteristics of the underground and of the storage volume is requested. This data are useful to the DST for the selection the applicable technologies.

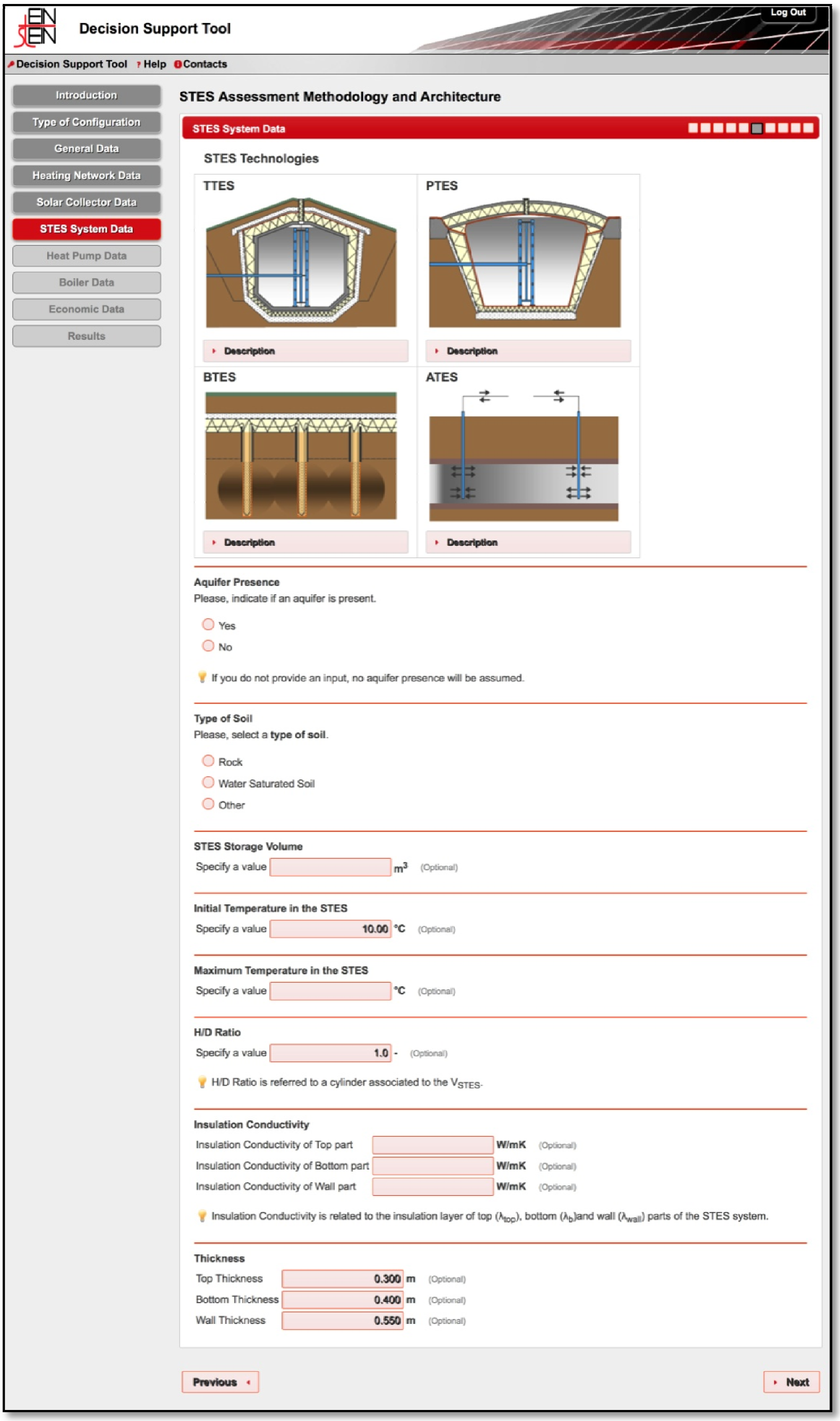


Figure 4.7. STES system Data dialog box.

7. *Heat Pump Data*: Data connected to the heat pump are required in this dialog box. All these data are optional and the User can insert values and detailed information about the heat pumps that intends to install, if available.

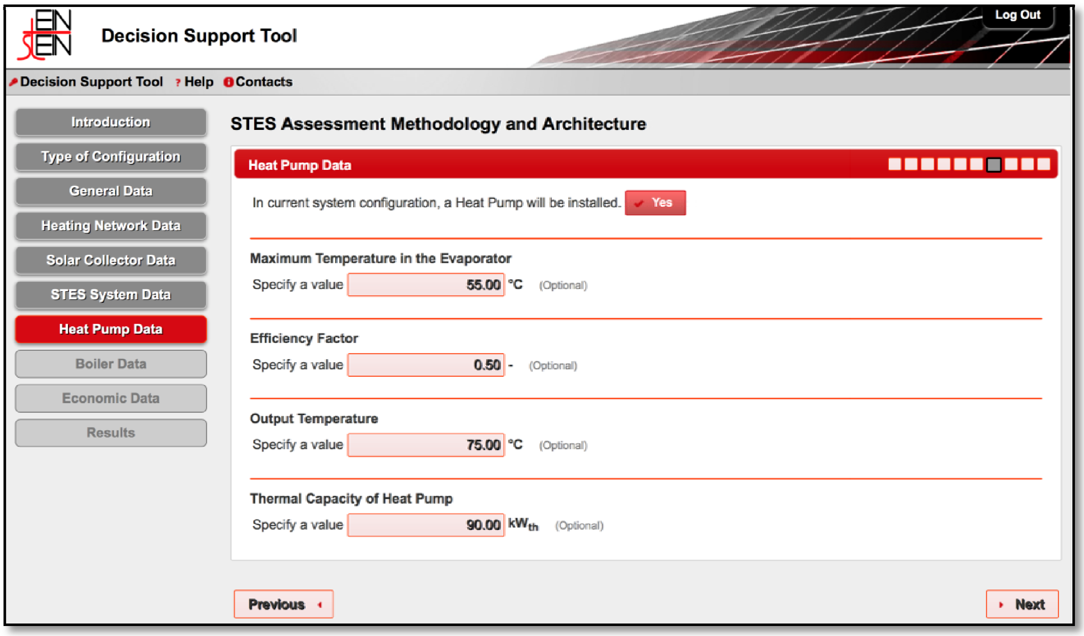


Figure 4.8. Heat Pump Data dialog box.

8. *Boiler Data*: In this dialog box, the energy source of the boiler that actually is used for heating the buildings is required and also its energy efficiency. If the User has not these information the DST will consider GAS as default energy source because is the most common one.

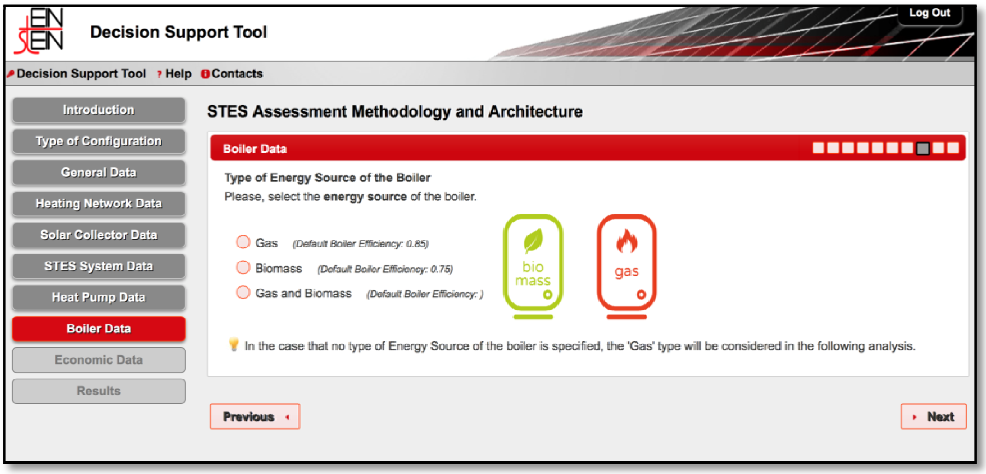


Figure 4.9. Boiler Data dialog box.

9. *Economic Data*: In this dialog box, the specific costs of the main system components and of the energy sources are required. These values are useful for he economic analysis of the system. This is the last dialog box of the DST input data section. In the bottom part of this box a red button is finally reported named “Elaborate Results”. Clicking on it the DST starts the data elaboration and the calculations useful for developing the results.

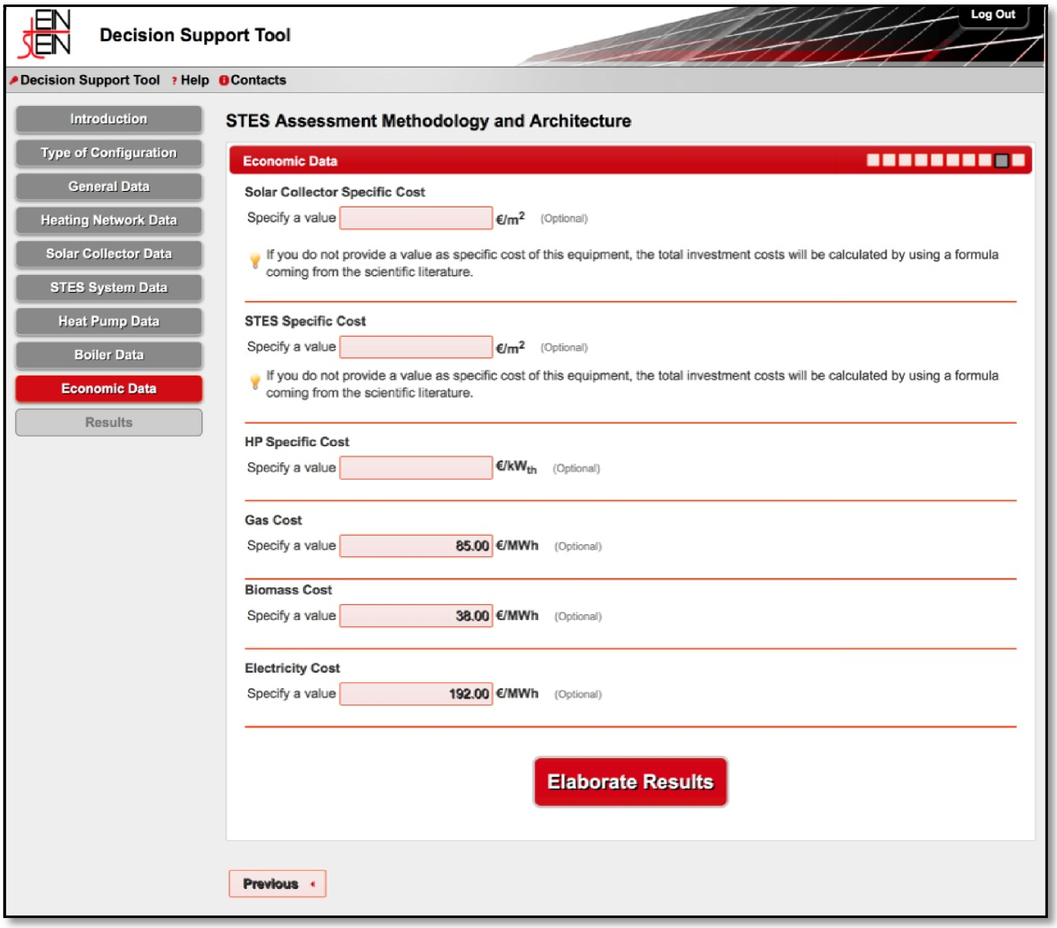


Figure 4.10. Economic Data dialog box.

10. *Results*: the last dialog box is dedicated to the presentation of the calculation results. This page has been based on “Tab” navigation: the information has been organized by grouping the different result items in specific sections of the Web page that can be navigated by the User simply clicking on the provided panels (tabs) such as General tab, Energy tab and Economic tab. In the General section a summary of the main input data inserted is provided and the results concerning the SC field and the STES system efficiencies as well as the temperature in the storage are shown. In the Energetic section the behaviours of the most important energy flows characterizing the integrated system are presented. In addition, in the last section, the economic results are shown. This kind of results organization is replicated for each system configuration identified by the elaboration process. When multiple configurations have been defined as tool outputs, the DST also provides an additional tab where these STES-based configurations are compared on the basis of a specific

set of relevant indicators. This comparison guides the User in the selection of the most suitable configuration. Finally, the User can download a report including all the results, modify some input data or reset the process in order to do a different evaluation simply using the three buttons in the upper part of the web page named “Create Report”, “Update Inputs” and “Reset Process”.

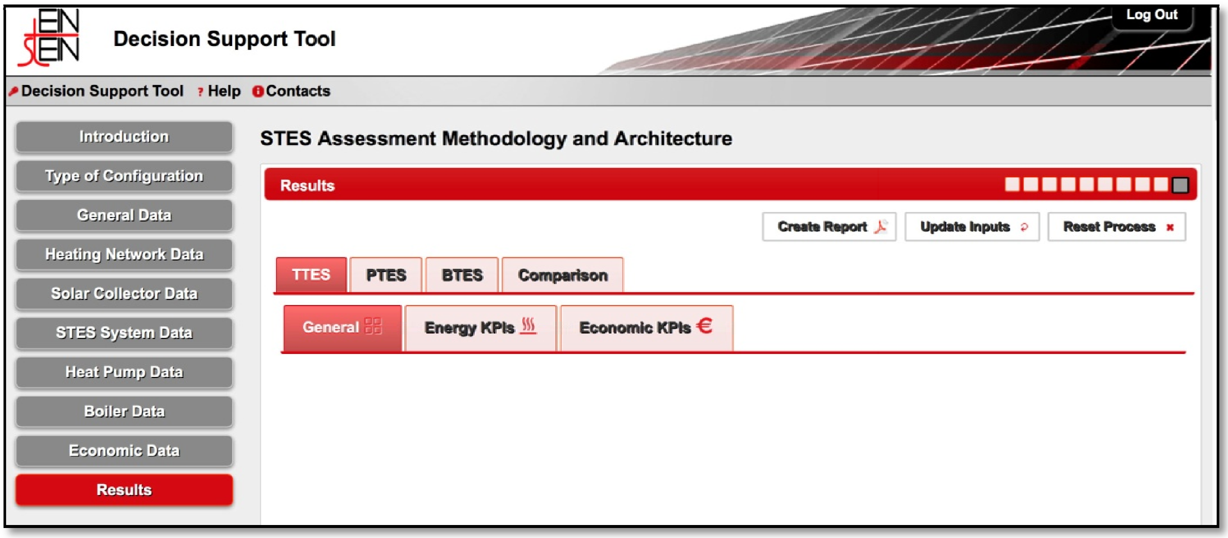


Figure 4.11. Results dialog box.

The User is guided in each step thanks to a Help including specific information about each requested data and details on how they are used in the calculations. Furthermore, an explanation about the DST results is provided. Finally, the Help also gives some additional information about the EINSTEIN Project.

Figure 4.12 DST Help.

5. POSSIBLE FUTURE DST IMPLEMENTATIONS

A brief overview of the aspects that could be investigated after the end of EINSTEIN project to maximize the exploitation of the DST is reported in this Chapter. In particular, some possible future implementations to improve the Decision Support Tool functionalities in order to enhance its potentiality and applicability covering a wider and wider range of scenarios, minimizing the gap between calculation results and real data are outlined. Several development lines can be undertaken starting from the valuable results achieved so far within the research project. Some of them require simply implementation of algorithms at the basis of the developed tool and others additional research efforts, as reported below:

- Not only Europe. The DST could evaluate the integrated system application not only in Europe but also in Asia and America. For this purpose, all the needed data such as climatic data and dwellings heating demand related to these countries should be added in the DST database.
- Hourly based calculations. The DST could perform hourly based calculations instead of daily based ones currently implemented. For this purpose hourly based space heating and Domestic Hot Water loads, solar irradiation as well as hourly climatic data are needed and should be added in the DST database.
- District Heating Network. The DST could analyse a real DH network considering the pipes path. This implementation allows the evaluation of the DH network concentrated and distributed pressure drops and the correlated values of DH pump head. Consequently, the electricity consumption of the pumps could be evaluated on hourly base reducing the error resulting by the assumption of a constant DH pump head. In addition, the costs associate to DH implementation could be considered thanks to the associate path.
- Storage Volume model. The DST could perform a different evaluation of the storage losses in function of the different STES technologies. For this purpose a new model for Pit Thermal Energy Storage, Borehole TES as well as Aquifer TES should be implemented.
- Daily heating time duration. The DST could consider different heating time with respect to the average time of 12 hours currently implemented. The time duration should be selected according to the location and the building heating technology. This data should be added in DST database.
- New buildings and Industrial applications. DST could evaluate the integrated system application not only in existing buildings but also in new ones as well as in industries. DST use in new buildings should be analysed with the actual tool logic implementing some data in its database. DST application in industries requires a higher research effort in order to consider the possible auxiliary heat coming from the industrial processes. Additional dedicated sections within DST could be implemented to cover different industry typologies.
- TRNSYS. A detailed modelling of the integrated system using a transient system simulation program such as TRNSYS needs to be performed for having a more accurate calculation of the required installation. For this purpose, additional research effort and a very high number of integrated system simulations for each specific case should be performed.

In addition, a validation process is also necessary for ensuring the reliability of the results coming out from the Decision Support Tool. Therefore, the usability of the DST has to be tested and validated in order to identify any adjustment needed in its algorithms. This process is currently on going and will be completed in next months; the results of this activity will be included in deliverable D5.8 “Report on the validation of DST at real case studies” due at the end of the project (M48). The approach identified for the validation process consists in performing a comparison among the collected data from the EINSTEIN demonstration installations monitoring in Poland and Spain and the outputs of the Decision Support Tool. In addition, a possible further action could be a validation using data from simulation performed in a transient environment such as TRNSYS.

6. CONCLUSIONS

The main objective of this task is the development of a Decision Support Tool (DST) for selection, design and evaluation of a STES system integrated with a solar plant, heat pumps and auxiliary boilers, in existing buildings. The tool is a Web-based application available on line for free.

The Users is lead through a series of steps to introduce data connected to the different components of the system. The DST performs the evaluation of the system from the energetic, environmental and economic point of view and guides the User in the identification of the most suitable technology to apply. In order to select the most suitable solution, some parameters are compared by the DST such as the solar fraction, the primary energy saving, CO_2 equivalent emission reduction indicator, the total investment cost and the heat cost. The criteria followed by the DST for the selection of the optimum technology consists in considering the technology that enables to achieve the highest Solar Fraction and Primary Energy saving with the lowest Heat Cost.

7. REFERENCE

[1] Business Energy Efficiency (BizEE) Software - http://www.degreedays.net/#generate, December 2014

[2] Photovoltaic Geographical Information System (PV GIS) online platform - http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=europe, December 2014

[3] European Environment Agency (EEA) – "Households Energy Consumption by End Uses" - http://www.eea.europa.eu/data-and-maps/figures/households-energy-consumption-by-end-uses-5 , 2009

[4] B. Lapillonne, K. Pollier, N. Samci, "Energy Efficiency Trends for households in the EU", Enerdata, Odyssee, 2014

[5] EINSTEIN Project – Effective Integration of Seasonal Thermal Energy System in Existing Buidings, "D5.5: Integration of subsystems and optimization", 2014

[6] M. J. Ahmad, G. N. Tiwari, "Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation", The Open renewable Energy Journal 2 (19-24), 2009

[7] I. Dincer, M. Kanoglu, "Refrigeration Systems and Applications", John Wiley & Sons, 2011

[8] A. Hlebnikov, A. Siirde, A. Paist, "The major characteristic parameters and present efficiency of the Estonian district heating networks", Doctoral school of energy and geotechnology, 2006

[9] United Utilities Water plc., "Design guidance for water mains and services on new development sites", Document Reference 20368, Issue 2, May 2012

[10] Sustainability Victoria, "Energy Efficiency Best Practice Guide: Pumping Systems", 2009

[11] ASHRAE Handbook, "Heating, Ventilating and Air-Conditioning Systems and Equipment - Chapter 11: District Heating and Cooling", 2008

[12] Intelligent Energy Europe, "Solar District Heating guidelines: Collection of fact sheets", WP3 – D3.1 & D3.2, Solar District Heating (SDH) Project, 2012

[13] A. V. Novo, J. R. Bayon, D. Castro-Fresno, J. Rodriguez-Hernandez, "Review of seasonal heat storage in large basin: Water tanks and gravel-water pits", Applied Energy 87 (390-397), 2010

[14] J. Milewski, M. Wolowicz, W. Bujalski, "Methodology for choosing the optimum architecture of a STES system", Journal of Power Technologies 94 (153-164), 2014

[15] D. Harvey, "A Handbook on Low-Energy Buildings and District-Energy Systems: Fundamentals, Techniques and Examples", Taylor & Francis

[16] P. Tymkow, S. Tassou, M. Kolokotroni, H. Jouhara, "Building Services Design for Energy Efficient Buildings", Taylor & Francis

[17] M. Guadalfajara , M. Lozano, L.M. Serra, "A simple method to calculate central solar heating plants with seasonal storage", Energy Procedia 48 (1096 – 1109), 2014

[18] E. M. Barber, J. Provey, "Convert your home to solar energy", The Taunton Press, 2010

[19] M. Guadalfajara , M. Lozano, L.M. Serra,"Geographic evaluation of central solar heating plants with seasonal storage for the residential sector in Europe", Aragon Institute of Engineering Research

[20] Eurostat portal - http://epp.eurostat.ec.europa.eu (http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_and_natural_gas_price_statistics)

[21] http://www.frisch.uio.no/ressurser/LIBEMOD/data/demand/prices---taxes/

[22] N. Badea, "Design for micro-combined cooling, heating and power systems: Stirling engines and renewable power systems", Spring, 2015