CombiSol

Standardisation & Promotion of Solar Combisystems

D4.1 : Specifications for monitoring, collection and evaluation of results

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CONTENTS

cip — Intelligent Energy Europe

Symbol list

Symbol	Definition	Unit
alt	altitude	10^3 m
C	consumption	kWh
Conc	concentration	%
Cf	specific heat capacity	kWh/kg.K
Cv	calorific volumetric value	kWh/m^3.K
I_{sol}	solar irradiation	kWh/m^2.d
P	pressure	Pa
Q	energy quantity, load, loss	kWh
Q_c	energy delivered by the solar collector	kWh
T	temperature	K
v	volume	m^3
$\dot{V}$	volumetric flow rate	m^3/s
W	electric consumption	kWh
θ	temperature	°C
Δt	time step	h
ρ	density	kg/m^3
Suffixes		
aux	auxiliary	
c	solar collector	
co	cold	
cor	correction	
e	external	
el	electrical	
g	gas	
H	space heating	
i	internal (temperature)	
l	loop	
ls	loss	
me	mean	
n	normal	
nd	need	
sol	solar	
wa	warm	
W	Domestic Hot Water	
*	used when a definition is slightly modified	
Fonts		
normal	calculated values	
bold	**identified or estimated values**	
italic	*measured values*	

Annual and monthly values:

In general, energy balances can be calculated on a yearly or monthly period, with same formula. If the annual formulas are ambiguous, the symbol **Σ** is placed before the concerned figure.

Table list

Figure list

Introduction

In order to be in coherence with the ranking and comparison criteria proposed in Task 26, a method for monitoring solar combisystems has been elaborated in the frame work of the Altener Combisystems project, which gives as an output a value for the annual fractional energy savings F_{sav} according to the Fractional Solar Consumption FSC [1]. This method is based on the measurements of monthly energy balances [3]. F_{sav} is evaluated by comparison between the auxiliary energy used by the SCS and the one used by a conventional system without solar collector, using the same energy.

FSC does not depend on the SCS and the auxiliary energy used. It only characterizes the solar potential compared to a reference consumption necessary for space heating and DHW production. It is for this reason that it doesn't take into account the real auxiliary energy used by the SCS.

In this document, the different categories of SCS are described, with regard to the monitoring possibilities. The list of data required and the place where measurements have to be done are given.

1. Classification of SCS with respect to monitoring

Three categories of solar combisystems can be met, according the way the auxiliary system is connected to the solar part of the plant.

1.1. SCS with separated auxiliary for space heating

This category contains SCS with an auxiliary space heating delivered by electrical heaters or a wood stove (or equivalent). It is almost impossible to measure correctly the used or delivered energy by a wood stove. So monitoring can only be made with an electrical auxiliary space heating. But of course, these SCS will also be able to be sold with wood as auxiliary energy for space heating.

1.2. SCS with integrated auxiliary for space heating

In this category, two alternatives can be found:

- SCS with an auxiliary burner integrated in the storage tank, where it is impossible to measure energy at the boiler outlet

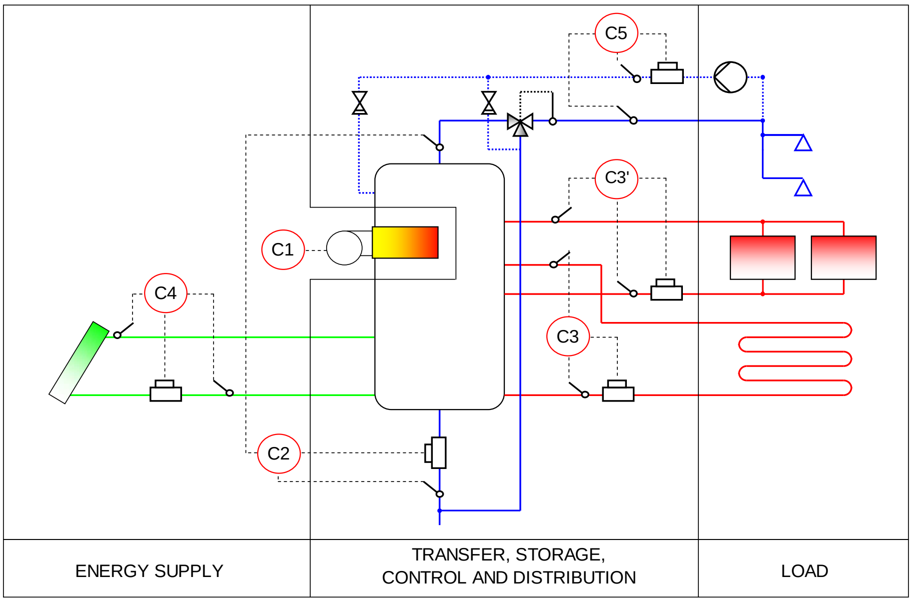

Figure 1: SCS with integrated auxiliary burner

- SCS with a remote auxiliary boiler, that can be :
    - o A wood boiler. In this case, it is almost impossible to measure energy at the boiler inlet: it is difficult to assess the exact amount of energy of the wood put in the boiler, because of the variation of its humidity and calorific value.

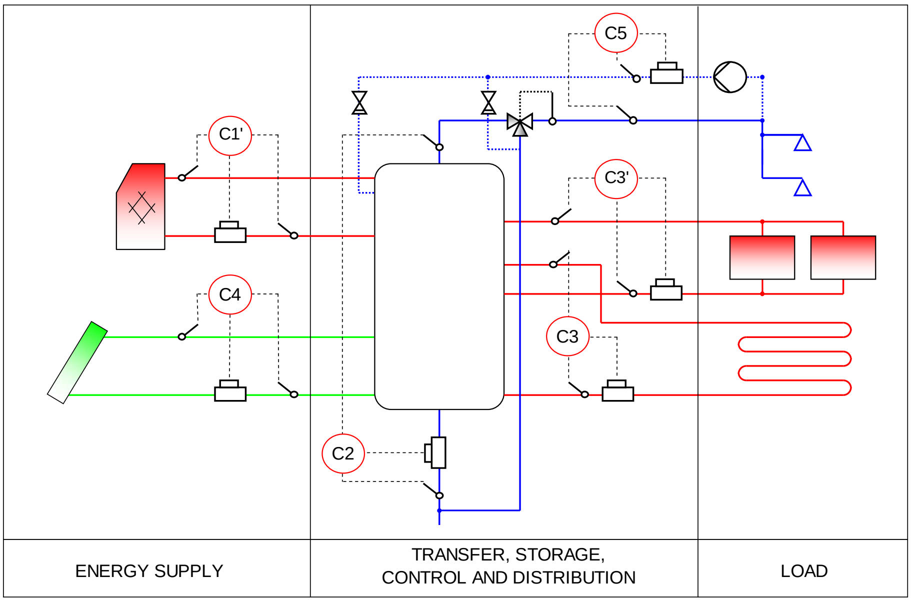

Figure 2: SCS with auxiliary wood boiler

- o An electric, oil or gas boiler. In this case, energy can be measured either at the inlet or at the outlet of the boiler.

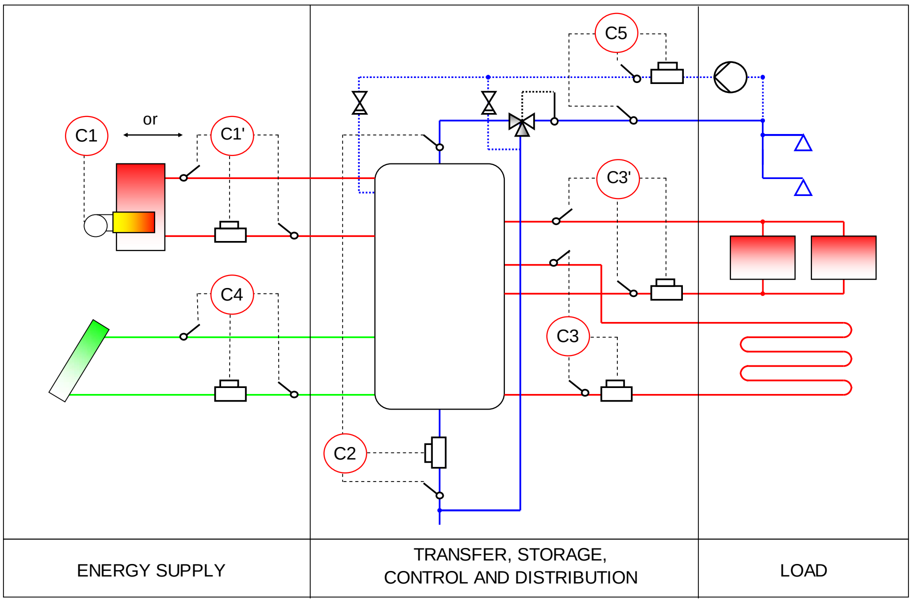

Figure 3: SCS with auxiliary electricity, gas or oil boiler

The choice between the two possibilities 1 and 1' will be made according to the boundaries of the system sold by the manufacturer. If a special auxiliary boiler is sold or recommended by the manufacturer, auxiliary energy should be measured at the boiler inlet. At the opposite, if an existing boiler is used, or if an auxiliary wood boiler is used, or if the boiler can not be considered as a part of the system, auxiliary energy should be measured at the boiler outlet.

2. Monitoring equipment

2.1. Location of required meters

The following table and diagram give a list of required heat meters and their location, according to the type of studied SCS, using the classification of task 26 [2].

Type	Auxiliary boiler input (1)	Auxiliary boiler output (1')	DHW (2)	Space heating loop (3)	Solar collector loop (4)	DHW loop, if present (5)
SCS with separated auxiliary for space heating	**Electricity meters for the heaters and for the auxiliary DHW tank**		**yes**	**yes**	yes	**yes**
SCS with integrated auxiliary burner	**Oil-meter or gas-meter**		**yes**	**yes**	yes	**yes**
SCS with wood auxiliary boiler		**yes**	**yes**	**yes**	yes	**yes**
SCS with coupled auxiliary oil- or gas-boiler	Oil-meter or gas -meter or electric-meter	**or** yes	**yes**	**yes**	yes	**yes**

+ indoor temperature, outside temperature, irradiation in the collector plane
Legend: **mandatory**, optional. ("yes" means "a heat meter is required")

Table 1: Required meters

The following table gives the list of measured data:

Symbol	Meaning	Unit	Location
C_{aux}	**auxiliary consumption**	**kWh**	**1 or 1'**
$I_{sol,c}$	**solar irradiation on the solar collector**	**kWh/m²**	**in the collector plane**
Q_W^*	**DHW load**	**kWh**	**2**
$Q_{H,inj}$	**energy injected in the space heating loop**	**kWh**	**3, 3'**
W_{sol}	**parasitic electricity consumption**	**kWh**	
Q_c	energy delivered by the solar collector	kWh	4
$Q_{ls,W,l}$	**heat losses of the DHW loop, if present**	**kWh**	**5**
θ_i	**inside temperature**	**°C**	
θ_e	**outdoor temperature**	**°C**	

Legend: **mandatory**, optional.

Table 2: Measured data

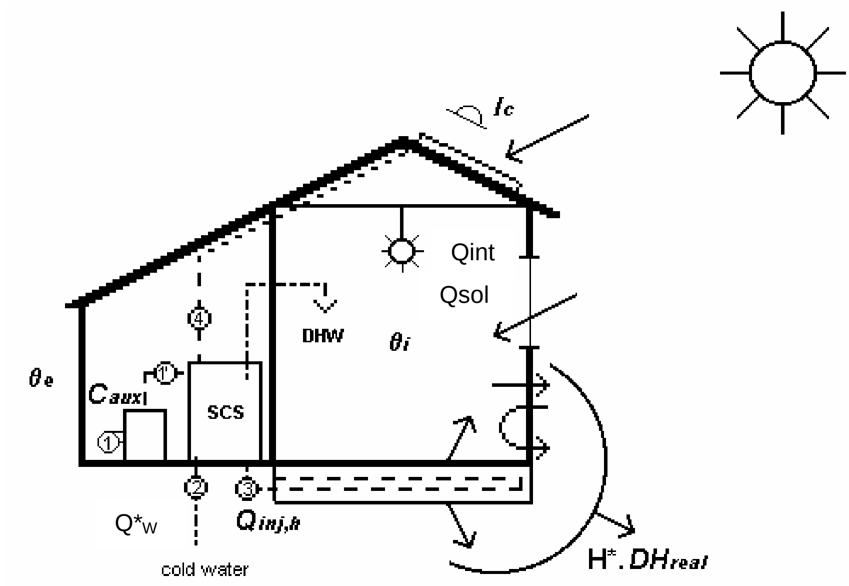

Figure 4: Location of the heat meters and other sensors

Type of auxiliary heater		Gas boiler	Oil boiler	Electric boiler	Heat Pump	Wood boiler
Solar collector loop	Flowmeter	1				
	T°sensor	2 into the pipes				
DHW load	Flowmeter	1				
	T°sensor	2 into the pipes				
DHW loop	Flowmeter	1				
	T°sensor	2 into the pipes				
Space heating loop(s)	Flowmeter	1 for each loop				
	T°sensor	2 into the pipes for each loop				
	Air T°sensor	1 for each loop				
Auxiliary heater	Flowmeter				1	
	T°sensor	1			2 into the pipes	
	Electric meter			1		
	Gas meter	1				
	Oil meter		1 or 2*			
Meteorological data	Air T°sensor	1				
	Pyranometer	1				
Parasitic electricity	Electric meter	1				
Data logger		1				
Electrical box		1				

* : 2 oil meters required if there is a return pipe from the boiler to the oil tank

Table 3: List of equipment according to the auxiliary energy used

2.2. Specification of sensors and meters

All sensors have to be installed according to the manufacturer's requirements, especially with regards to the length of straight pipes needed before and after the flow meters, the position of these meters (vertical or horizontal, the direction of flow in the meters, etc…)

Flow meters have to be compatible with the antifreeze fluid used in the collector loop and eventually in other loops (case of Direct Solar Floor)

	Specifications	Main suppliers
Hydraulic flowmeter	output pulses : max 1 l/pulse Volumetric flowmeter for DHW able to mesure low flows For solar collector loop, if possible avoid pieces en movment (protection against high temperatures) B or C Class	ABB Actaris Dalectra Ennovatis Hydrometer Sappel Sensus metering system Sontex Wateau - Elster
Gaz flowmeter	G4 type	Actaris NZR Sappel
Oil flowmeter	VZ04 type	Aquametro Sappel
Temperatures	PT 1000 A Class Inserted in pipes Calibrated 2 by 2 for each loop	Btib Thermokon Ennovatis Prosensor TC SN Microlide
Electric meter	Output pulses : 1 or 10 Wh/pulse	Actaris Chauvin-Arnoud Conrad Delta Dore Eltaco Huter Legrand Merlin Gerin MCI NZR
Irradiation	Output 0-100 mV Accuracy better than 5%	INOR Solems Tritec

Table 4: Specifications and suppliers

2.2.1. Flow meters

Flow-meters should be located on pipes where the flow is as constant as possible. So, when monitoring a loop with a three-way valve, the flow-meter should be located in the same section as the pump.
Accuracy is defined according Table 5. In this table, q_n is the nominal flow of the flow meter. Accuracy is ± 5 % between q_{min} and q, and ± 2 % between q_t and q_{max} = 2 q_n.

Classes	Flows	Hot water	Cold water
Class A	q_{min} q_t	0.04 q_n 0.10 q_n	0.08 q_n 0.20 q_n
Class B	q_{min} q_t	0.02 q_n 0.08 q_n	0.04 q_n 0.15 q_n
Class C	q_{min} q_t	0.01 q_n 0.06 q_n	0.01 q_n 0.015 q_n
Class D	q_{min} q_t	0.01 q_n 0.015 q_n	

Table 5: Class of flow meters

The maximum weight of a pulse should be 1 liter.

2.2.2. Choice of temperature sensors

Temperature sensors should be chosen so as to have the smallest response time. This is very important for the Domestic Hot Water loop, where there is no continuous flow, and where the water temperature falls down when there is no draw-off. So in order to minimize the measurement error made when a water draw-off begins, the temperature sensor should be able to give very quickly an accurate measure. Temperature sensors placed into the pipes should be preferred to contact sensors. They should be calibrated 2 by 2 for each loop.

Accuracy is defined according Table 6, where t is the temperature (℃):

Class	Accuracy (°C)
A	0.15 + 0.002 |t|
B	0.3 +0.005 |t|

Table 6: Class of temperature sensors

2.2.3. Choice of gas meter

Accuracy of the gas meter should respect Figure 5, and the maximum weight of a pulse should be 0,01 m^3. The size of the gas meter should be chosen according Table 7 and the caloric value of the gas used:

- o Natural gas : ≅ 11 kWh/Nm^3
- o Propane : = 23.7 kWh/m^3 (ISO 2533)

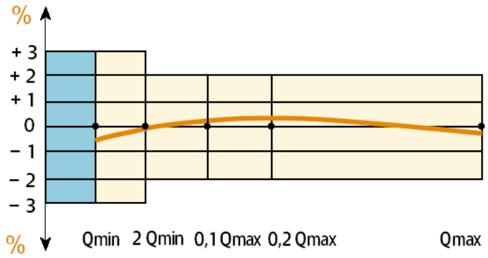

Figure 5: Accuracy of gas meters

	Qmin (m^3/h)	Qmax (m^3/h)
G 1,6	0,016	2,5
G 2,5	0,025	4
G 4	0,040	6

Table 7: Size of gas meters

2.2.4. Choice of oil meter

Accuracy of oil meters is equal to + 1 % / - 2 % between Q_{min} and 2 Q_{min} and ± 1 % between 2 Q_{min} and Q_{max}, with:

- Q_{start} = 0,4 l/h
- Q_{min} = 1 l/h
- Q_{max} = 80 l/h

2.2.5. Location of irradiation sensor

The irradiation sensor should be placed near the solar collector, with the same orientation and the same tilt angle, so that it measures exactly the global irradiation "seen" by the solar collector. If it is installed this way, the sensor will take into account the shadow created by the obstacles of the surrounding.
Accuracy should be better than 5 %.

2.3. Data logger

2.3.1. Data collection and storage

All sensors and meters are connected to a data logger, which allows:

- Data collection on a short time step (< 1 minute)
- Calculation of energy in the different hydraulic loops (Domestic Hot Water, space heating loop(s), collector loop, eventually auxiliary boiler loop). These calculations are usually done on a minute time step.

Two options are possible for data storage:

- Measurements are stored in the data logger, and transferred to a remote computer where energy calculations are performed
- Measurements and energies calculated are stored in the data logger. This allows generally to calculate energy with a small time step.

2.3.2. Data downloading

Data can be stored in the data logger and downloaded in a memory stick or a PC connected regularly to the logger. But this option is not flexible, since all modifications have to be done when connected.

More convenient is to have an Internet connection.

With a single software tool, it is possible to configure the remote loggers, to download the configuration file or, conversely, upload the configuration data of an existing unit to initialize a new, similar site simply by copying files. It is also possible to view snapshot values and historical data (measurements, instructions, alarms, etc.), to export data to a third-party package (spreadsheet, special processing software, etc), and to issue control commands and setpoints. This is the cheapest way to get data, but it needs that a central PC is regularly connected to the remote units.

Alternatively, it is possible to use a specialized software for multiple sites supervision, which allows to have a more automated supervision on multiple data loggers.

Data loggers can normally be connected to an internet box, but this is not so easy to do because each provider has its own connection protocol, and some problems can be met. To avoid conflicts, it is easier to use a GSM for the connection.

Suppliers	Model	Specifications
NAPAC	IRio + Kerwin	CPU 16 analog inputs for temperature sensors, irradiation sensor, etc… 8 digital inputs for flow meter, electricity meter, gas or oil meters, etc. GSM-Modem + cable
ENNOVATIS	Smartbox	
B&R	System 2003	

Table 8: Specifications for the data loggers

3. Particular situations

3.1.1. Energy calculations

For all loops, energy Q measured during a time step (Δt) is given by equation 1:

Equ. 1 $$Q = \Sigma\ \dot{V} \cdot \rho[\theta_{co}] \cdot Cf\ [\theta_{me}] \cdot (\theta_{wa} - \theta_{co}) \cdot \Delta t$$ (kWh)

With

θ_{wa}	flow warm temperature	(℃)
θ_{co}	return cold temperature	(℃)
$\dot{V}$	volumetric flow rate, measured on the cold pipe	(m^3/s)
$Cf[\theta_{me}]$	specific heat capacity, calculated for θ_{me}	(kWh/kg.K)
$\rho[\theta_{co}]$	density, calculated for θ_{co}	(kg/m^3)
Δt	time step	(s)

The specific heat capacity Cf of the antifreeze fluid has to be calculated in the data logger with the mean temperature θ_{me}, using a formula given by the manufacturer of the fluid.

Equ. 2 $$\theta_{me} = (\theta_{wa} + \theta_{co}) / 2$$ (℃)

Equ. 3 $$Cf[\theta_{me}] = f\ (\theta_{me}, Conc)$$ ($kWh/m^3.K$)

With Conc concentration of glycol in the mixture (%)

3.1.2. Physical properties of the antifreeze fluid

The antifreeze fluid used in SCS is usually a mixture of pure water and monopropylen glycol. For a better accuracy, it is recommended to use the physical properties of the fluid provided by the manufacturer.

If these data are not available, for a standard mixture, the density and the specific heat capacity can be approximated using following polynom:

Equ. 4

$$f[\theta,Conc]=a+b\left(\frac{Conc}{100}\right)+c\left(\frac{273.15}{(\theta+273.15)}\right)+d\left(\frac{Conc}{100}\right)\left(\frac{273.15}{(\theta+273.15)}\right)+e\left(\frac{273.15}{(\theta+273.15)}\right)^2$$

With	θ	temperature of the fluid	(°C)
	Conc	concentration of glycol in the mixture	(%)

	Unit	a	b	c	d	e
density	kg/m^3	508.41109	-182.4082	965.76507	280.29104	-472.2251
specific heat capacity	kJ/kg.K	4.4764	0.60863	-0.71497	-1.93855	0.47873

Table 9: Physical properties of the antifreeze fluid

3.1.3. Physical properties of water

Density and specific heat capacity of water can be approximated using following polynom:

Equ. 5 $$f[\theta]=a+b\,\theta+c\,\theta^2+d\,\theta^3+e\,\theta^4+f\,\theta^5$$

With θ temperature of the water (°C)

	Unit	a	b	c	d	e	f
density	kg/m^3	999.85	$6.187\ 10^{-2}$	$-7.654\ 10^{-3}$	$3.974\ 10^{-5}$	$-1.110\ 10^{-7}$	
specific heat capacity	kJ/kg.K	4.217	$-3.358\ 10^{-3}$	$1.089\ 10^{-4}$	$-1.675\ 10^{-6}$	$1.309\ 10^{-8}$	$-3.884\ 10^{-11}$

Table 10: Physical properties of water

3.2. Gas measurement

Measurements made with a volumetric gas meter give the amount of gas consumed v_g. In order to get the energetic content of this consumption, v_g has to be multiplied by the calorific volumetric value of the gas Cv_g, and by a correction factor C_{cor}.

Equ. 6 $Q_g = v_g * Cv_g * C_{cor}$

Two types of corrections are met, according to the type of gas and the standard used:

- A gas volume given according DIN 1343 standard is called "Normal volume" : 273.15 K (0°C), 101 325 Pa
- A gas volume given according ISO 2533 standard is called "Standard volume" : 288.15 K (15°C), 101 325 Pa

Equ. 7 $C_{cor} = (T / T_{cor}) \times (P_{cor} / P_n)$

Where

P_n pressure at an altitude of 0 m = 101325 Pa =1.01325 bar
T normal or standard temperature (T_n = 237.15 K or T_s = 288.15 K), according to the standard used
P_{cor} absolute pressure at the gas meter level = atmospheric pressure at the altitude of the monitored plant + pressure value after the gas pressure regulator (distribution pressure)
T_{cor} absolute temperature at the gas meter level = 273.15 + T℃. T_{cor} is measured continuously with a sensor located near the gas meter.

Theoretically, the local atmospheric pressure around the gas meter should be measured continuously. But this cannot be done in an acceptable cost in individual plants. Therefore some simplification is introduced:

The atmospheric pressure is only corrected considering the altitude, and the effect of the weather on the atmospheric pressure is neglected, considering that good weather periods will be compensated by bad ones.

The atmospheric pressure can be calculated with following equation:

Equu. 8 $P_{cor} = 1013.5394 - 119.9818\ alt + 5.2121\ alt^2$ (bar)

With alt = altitude in thousands of meters

Examples

Measured gas natural gas
Measured volume 10 m^3
Altitude 500 m
Mean value of the absolute temperature at the gas meter level : T_c = 20 ℃ = 293.15 K
Upper calorific value 10.7 kWh/Nm^3

$P = 1013.5394 - 119.9818 \times 0.5 + 5.2121 \times (0.5)^2 = 955$ mbar
$P_{cor} = P + 21 = 955 + 21 = 976$ mbar
$T = 273.15$ K
$C_{cor} = (T / T_{cor}) \times (P_{cor} / P_n) = (273.15 / 293.15) \times (976 / 1013.25) = 0.898$
Lower calorific value : $Cv_g = 10.7 / 1.11 = 9.640$ kWh/Nm^3
Energetic content of the consumed gas : $v_g \times Cv_g \times C_{cor} = 10 \times 9.64 \times 0.898 = 86.52$ kWh

Measured gas propane
Measured volume 10 m^3
Altitude 300 m
Mean value of the absolute temperature at the gas meter level : T_c = 15 ℃ = 288.15 K
Lower calorific value 23.7 kWh/m^3 (ISO 2533)

$P = 1013.5394 - 119.9818 \times 0.3 + 5.2121 \times (0.3)^2 = 978$ mbar
$P_c = P + 21 = 978 + 37 = 1015$ mbar
$T = 288.15$ K
$C_{cor} = (T / T_c) \times (P_c / P_n) = (288.15 / 288.15) \times (1015 / 1013.25) = 1.002$
Lower calorific value : $Cv_g = 23.7$ kWh/m^3
Energetic content of the consumed gas : $V_{g,m} \times Cv_g \times C_{cor} = 10 \times 23.7 \times 1.002 = 237.47$ kWh

The correction factor C_{cor} can be directly computed in the data logger, using equations 7 and 8, and the measured value of the temperature T_{cor}

3.3. Specifications of the gas distribution

Following tables give the specifications of the gas distribution in the participating countries.

3.3.1. Natural gas

	Calorific value	Pressure delivered by the pressure regulator
Austria	Lower calorific value in Styria is 10.03 kWh/Nm3 (per norm m3)	Usually 22 mbar
France	The calorific value can be found on the gas bills of the owner of the monitored house. The given value is the **upper** calorific value at normal conditions (DIN 1343). It can change over the year according the mix of gas coming from different regions (Russia, North Africa, etc…). The corresponding **lower** calorific value is obtained by dividing the **upper** calorific value by a factor 1.11	Usually 21 mbar
Germany	On the gas bills of the owner of the monitored house, the conversion factor C_{con} = Cv_g x C_{cor} is found. The calorific value Cv_g can change over the year according to the mix of the gas coming from different regions. The correction factor C_{cor} is computed according to equation 7.	Usually 22 to 23 mbar.
Sweden	Not relevant for Swedish conditions (gas network is very little in Sweden and about 1% of systems have gas as auxiliary energy source)	

Table 11: Natural gas specifications

3.3.2. Propane

	Calorific value	Pressure delivered by the pressure regulator
Austria	The **lower** calorific value at standard conditions (ISO 2533) is 23.70 kWh/m^3	Does not exist
France		Usually 37 mbar
Germany		Not relevant
Sweden		Not relevant

Table 12: Propane specifications

3.4. Oil measurement

The fuel meter must be located preferably downstream of the pump and upstream of the valve in order to measure only the actual fuel consumed. In this case, it is necessary to verify that the operating range of the meter fits with the work pressure of fuel burner

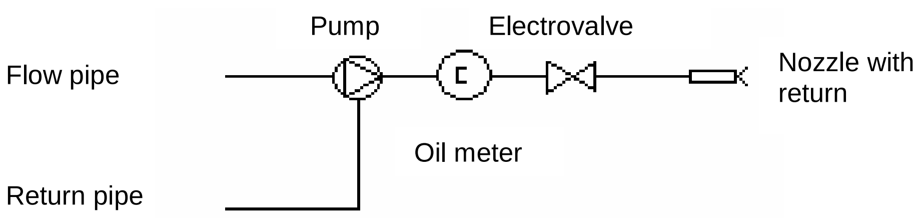

Figure 6: Location of the oil meter

Otherwise, or in the case of inability to locate the oil meter at this point, it is necessary to install two oil meters, one on the flow pipe, and the other on the return pipe.

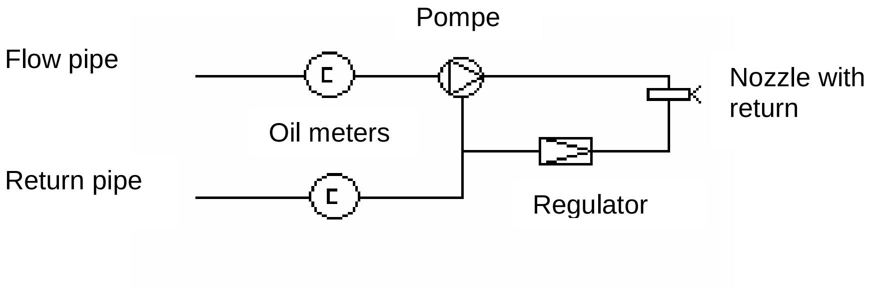

Figure 7: Location of the oil meter

The installation of a fuel meter is accompanied by the installation of an adapted filter, located upstream of the meter. In the case of an installation on the nozzle pipe, it is necessary to verify that the installed filter can withstand the pressure. Otherwise, the filter can be installed upstream of the pump.

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