STRATEGIES USED FOR DEVELOPING MICRO-CCHP STRUCTURES IN RESIDENTIAL AND PUBLIC BUILDINGS

Nicolae BADEA, Nelu CAZACU, Ion VONCILA,
Ion PARASCHIV, Marcel OANCA

„DUNAREA DE JOS” University of Galati, Domneasca Street, No.47, 800008-Galati,
Tel/Fax: 460182
e-mails: nicolae.badea@ugal.ro, nelu.cazacu@ugal.ro, ion.voncila@ugal,
ion.paraschiv@ugal, marcel.oanca@ugal

Abstract. The current paper deals with the efficient use of the fossil fuels in the context of DER/DG concept through a unitary approach of the necessary electrical power and thermal energy of an urban residential quarter and proposes the use of micro-CCHP (trigeneration of electrical power, heat and cooling) systems. An analysis of the consumption structures of electrical power and natural gas is provided for the specific conditions of Romanias’ South-Eastern regions. The paper contains a case study which highlights the imbalance between electrical and thermal consumption throughout a year. It also includes a strategy of designing the micro-CCHP systems according to the ratio between generated electrical power and thermal power (P/Pth) by the system and the same ratio for the consumers previously analyzed. The paper presents a proposed structure of micro-CCHP which has, as basic, thermal engines with fuel cells as well as the overall thermal result of the systems’ forecast for the critical seasons - winter/summer.

Keywords: cogeneration, trigeneration, fuel cell, renewable energy, eficiency.

1. INTRODUCTION

In the present context of the fossil fuel supplies reduction and the greenhouse effect growth, one can notice the emergence of new concepts that tackle alternative solutions for energetical power production (sources of renewable energy) and try to optimize the already existing technologies for using fuel. An important concept for the European Union, introduced by the 8/2004 direction is the promotion of the freezing process (CHP) through the decentralization of the electrical power and thermal energy production. This direction encourages the distributed energetic generation (Distributed Generation-DG) or the decentralized one (Decentralized Energy Resources-DER) at the consumer’s level. In the context of the generation process – as a new feature – introduced in order to meet the quality and comfort criteria in residential buildings, it is the appearance of trigeneration. Trigeneration implies the use of heat for heating the residence during winter and the possibility of cooling the space in summer.

The cogeneration/trigeneration systems (CHP/CCHP) used for the residential section should be elaborated and projected with the purpose of having the ability to simultaneously produce heat, cooling and electrical power from only one energy source.

This paper was recommended for publication by Marian Gaiceanu

2. STRUCTURE OF THE MICROCCHP SYSTEMS

An integrated co/tri-generation system uses a basic thermal engine with a generation or a fuel cell directly, heat switcher for integrating the heat, cooling through thermal activation and demoistening. These components are integrated as a block with the necessary electrical and mechanic components. The CHP/CCHP type is determined by the power generation equipment type used because they impose the heat recuperation technology.

There are different CHP/CCHP structures but the most currently used is that with the separation of power generation from heat/cooling generation (Figure 1).

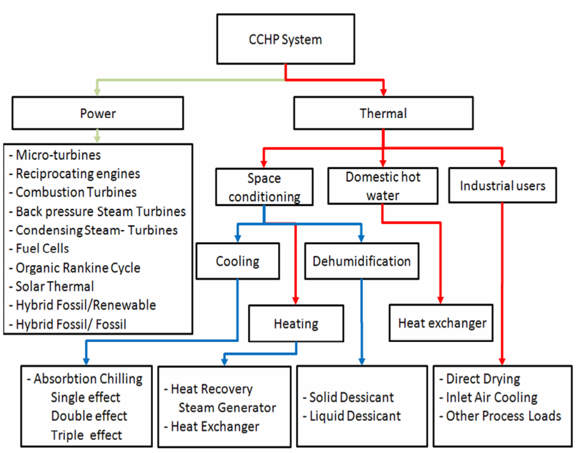


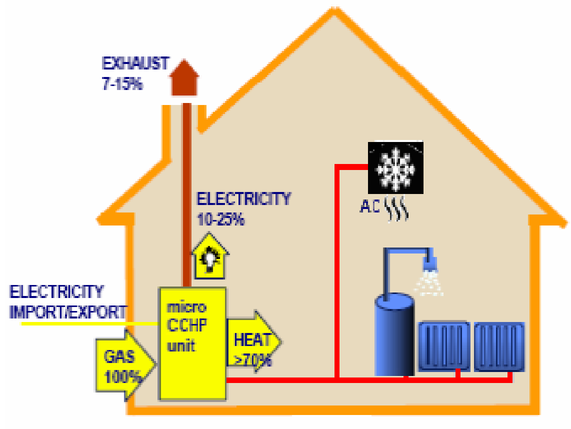
Fig. 1. Components of CCHP systems –technologies and applications (WADE, 2002).

An objective of CHP/CCHP systems is the diversification of energy sources and their security. Cogeneration/trigeneration applied to residences cover the usual electrical power needs < 5 kWe and for the thermal needs <25 kWth.

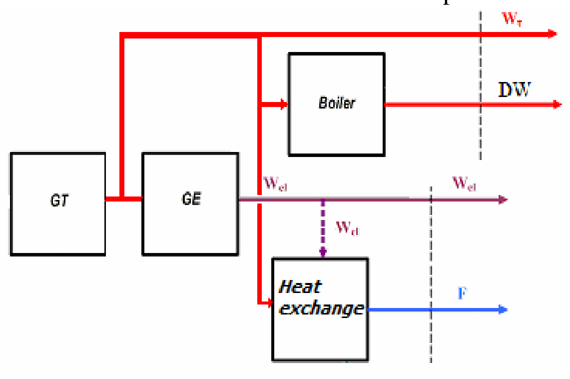
The sketch of a CCHP residential system and of its energetic flows is shown in Figure 2.

3. STRATEGIES USED FOR DEVELOPING MICROCCHP STRUCTURES IN RESIDENTIAL AND PUBLIC BUILDINGS

For comparing the trigeneration procedures and their performances the performance indicators of trigeneration production are defined in comparison to the separate production of different energies. The performance indicators of production systems in trigeneration are the ratio electrical power/ thermal energy; electrical efficiency of production in trigeneration; fuel economy: thermal efficiency; cooling efficiency; global efficiency. The first performance indicator of the trigeneration production system is the ratio between electrical power and useful thermal energy P/Pth.



a. The sketch of m-CCHP consumption



b. energetic flows

Fig. 2. CCHP residential system

Establishing the ratio P/Pth as accurately as possible represents the most important task in projecting a CHP/CCHP system. We can adapt a CHP/CCHP equipment by knowing the P/Pth ratio of the residential demands.

According to 377/90 CEE direction from June 29th 1990, dealing with improving the transparency of gas and electrical power prices, A.N.R.E and A.N.R.G.N respectively, send to the National Institute of Statistics the registered prices at the beginning of each semester (NIS, 2007; Order no 1353/2007; NIS, 2008).

On the electrical side 5 standard domestic consumers (codified according to the residence surface: Da-50m^2, Db-70 m^2, Dc-90 m^2, Dd-100 m^2, De-120 m^2) are defined. Each category is charactherized by the anual consumption and the standard dwelling equipped with electrical devices

The consumptions are annual and have the values (NIS, 2007) for Da<1000kWh, Db=(1000-2500)kWh, Dc=(2500-5000)kWh, Dd=(5000-15000)kWh, De>15000kWh.

From the natural gas consumption point of view there are three categories of final domestic consumers, each category being characterized by the annual consumption (D1=5540kWh, D2=27700kWh, D3=83100kWh).

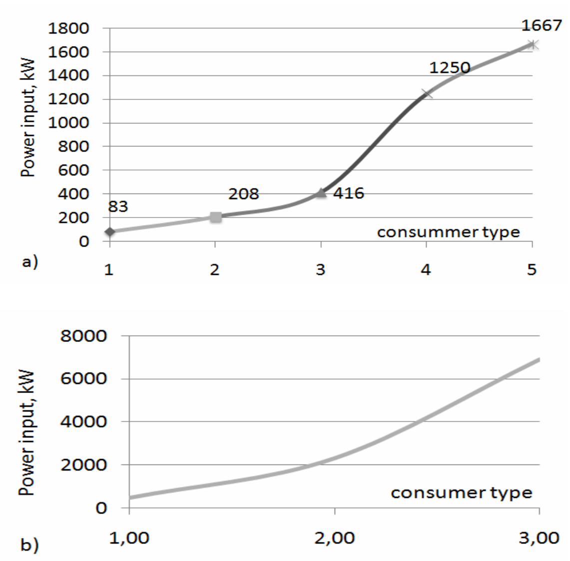


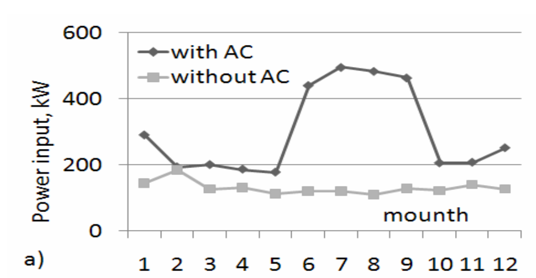
Fig. 3. a) electrical power (ANRE), b) gas (ANRGN) consumptions

From these data results a medium monthly consumption for each standard consumer, consumption shown in Figures 3A and 3B. From these data results P/Pth ratios Table 1) with extreme values between 0,1-5,42.

Table 1

Consumers	P/Pth		
	D1	D2	D3
Da	0,18	0,04	0,01
Db	0,45	0,09	0,03
Dc	0,90	0,18	0,06
Dd	2,71	0,54	0,18
De	5,42	1,08	0,36

Real electric power and thermal energy costs for domestic consumers have variables depending on the season, month and even hourly variations. The difficulties in designing the micro-CCHP systems come from the poor correlation of the electrical consumptions and the thermal ones due to variabilities in consumption of a dwelling. In order to avoid this monthly variability we have monitored the consumption in 2007 of some domestic consumers split in two groups –dwelling generating station system (CT) and respectively connected to the centralized heating system (SC) with and without air-conditioning system (AC). Monthly electrical consumption variation for the due categories of consumers are shown in Figure 4.



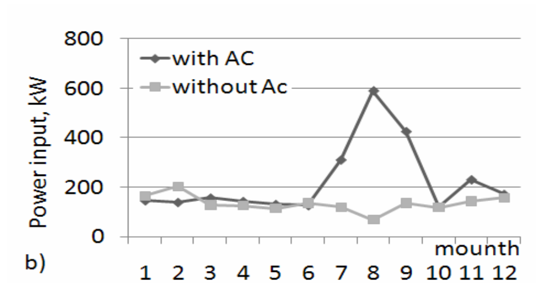


Fig. 4. Electrical power consumptions a) SC, b) CT

A comparative analysis indicates greater electrical power consumption values for AC consumers during summer, differentiated according the use of the AC. Excepting summer, the average monthly electrical power consumption keeps itself between 100 and 200 kWh. The thermal energy consumption – highlighted in Figure 5 – indicates lower avarage multiannual values for CT consumers in comparison with those connected to the centralized heating system SC.

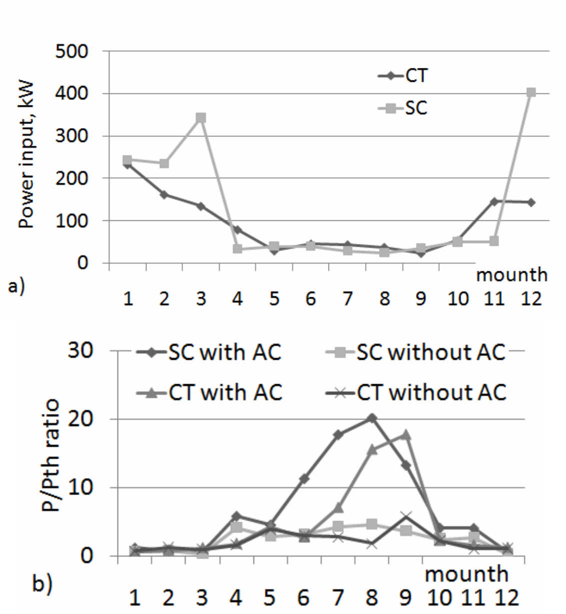


Fig. 5. a) Thermal energy costs; b) P/Pth ratio

Monthly variability of a P/Pth ratio is considerable as it is between 0,3 and 5 for consumers without air-conditioning. For the connected centralized heating system the consumed power curves are indicated in Figure 6.

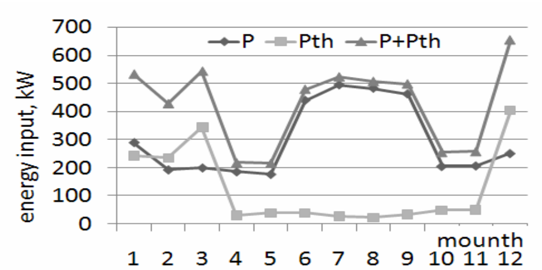


Fig. 6 Electrical power and thermal energy consumptions for dwelling connected to the SC.

The design of micro-CCHP systems is done taking into consideration the following strategies:

- The first strategy when designing the structures for trigeneration systems has as base line the electrical system which can cover the local consumption of the dwelling, including the maximum of energy during summer. This strategy – in designing a system – leads to 2 variants regarding the functioning of micro-CCHP: a) the system functions at maximum power which makes possible the delivery into the network of a certain electrical power quantity, using an adequate protocol (difficult to be attained in actual conditions); b) the micro-CCHP system functions following the electrical load. In both situations with a given P/Pth ratio, from the cogeneration central results a certain amount of heat as Pth=f (p) which implies either stocking the amount of heat or dispersing it into the surrounding climate because Pth consumption of the dwelling can differ from the quantity of produced thermal power. Stocking thermal energy is more difficult.

- The second strategy in designing the structures for trigeneration system is to take as basis the thermal load of the micro-CCHP system which has its maximum value during winter. In this case the central functioning should be with monitoring the thermal load. The electrical power produced by the micro-CCHP can be stocked in accumulators or delivered into the network. The electrical power consumption increases during summer due to air-conditioning systems supplied by the network. The micro-CCHP system suffers because of the modification of the P/Pth ratio in winter/ summer which leads to global inefficiency. During summer the air-conditioning system should be with thermal activation.

A new strategy of the present research group is based on maintaining the ratio P/Pth as constant as possible and meeting the residential consumers’ demands by balancing the thermal load through renewable energies. This strategy is based on technical data from the main basic engines which can produce electrical power and thermal energy in a constant P/Pth ratio.

The proposed strategy does not take into consideration the electrical consumption peaks of a dwelling (the residential consumers’ needs) but it is based on the average multiannual electrical consumption values. The consumption peaks are ensured by using some electrical power as well as thermal energy stocking elements. From a thermal point of view coverage of consumption peaks can be made by using a heat acuumulator which can take the excess of solar heat and the electrical power consumption peaks can be compensated by the energy stocked in the accumulator’s batteries. The CCHP system can ensure the balance of thermal load by cooling during summer through thermal activation technologies for cooling systems as opposed to traditional mechanical compression (air-conditioning obtained from thermal energy). In this way the electrical power need becomes uniform (P) and the heat/cooling demand (Pth) is greatly reduced making it possible for a convenient P/Pth ratio to be chosen for the trigeneration system. A P/Pth ratio which is as constant as possible is a demand for choosing a CCHP system.

4. STRUCTURES DESIGNED FOR THE TRIGENERATION SYSTEM (MICRO-CCHP) IN ORDER TO ENSURE THE QUALITY CRITERIA

In the present paper the following preliminary variants of micro-CCHP system structures are proposed taking into consideration studies and analyses from different perspectives.

The system structure proposed takes into account the evolution and technologies from the fuel cell domain.

Using them when designing a micro-CCHP relies on the following:

- the fuel cell capacity to generate electrical power
- the possibility of using energy under the form of heat in the heating/cooling system
- the possibility of using complementary solar energy under the form of heat to cover the low values of the P/Pth ratio specific today for urban residencies
- refrigerating system using a heat pump

For the fuel cell of the PEMFC type reforming can be done by using low temperature steam (<200ºC) in specific reduction reactions. It is recommended filtering the obtained mixture in order to reduce as much as possible the CO concentration (it has a noxious effect on the fuel cell). The installed maximum power of the micro-CCHP is 3…5 kWh electrical and 25 kWh thermal. (Kim D.S.,2005; Hoogers G, 2003).

The system is designed to cover the maximum electrical power need through the project aim (3...5 kWe). In the conditions of a 40...60% output and taking into consideration the aging of the fuel cell, one can expect a 40% output throughout its entire functioning cycle. In this case the recuperation of the residual heat (approx. 75%) is done through the systems:

- With heat change for cooling water as well as for cooling oil and keeping the engine temperature at 84.

- With heat change for burned gas from the evacuation and using a changer of maximum efficiency.

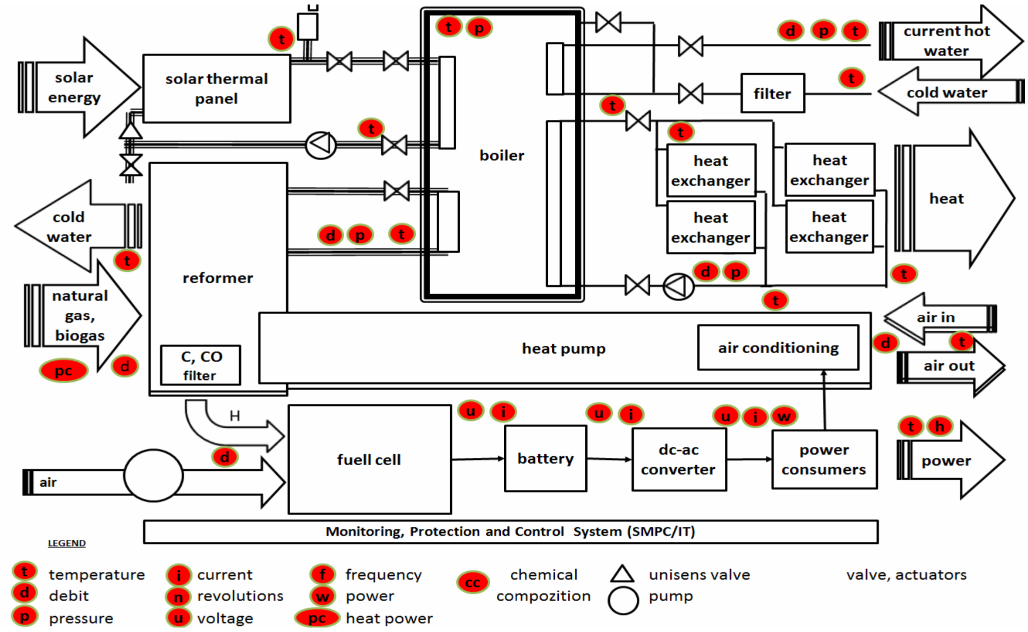


Fig. 8. Micro-CCHP system structure having as basic thermal engine the fuel cell (PEMFC)

Recuperated heat is stocked into the boiler which is full of water at maximum 90ºC. An additional solar energy system with a complementary source which supplies heat to the same boiler using high efficiency (75...95%) solar thermal panel is considered for use in order to bring the P/Pth ratio at present needs. The use of the solar thermal panels is useful when electrical power need is reduced and heat need is high, as well in the case when the boiler plays the part of a thermal energy accumularor (diminishing night/day differences). Through SMPC one intends to maximize solar energy use. For the micro-CCHP the variability of electric and thermal consumptions (night/day, winter/summer) is reduced through electric and thermal accumulation systems (accumulation batteries and boiler). The energetically balance for winter/summer is presented in the Annex 1. Keeping water hot – in closed circuit – is done with heat changing which takes heat from the boiler. The necessary electrical power for residual consumption is obtained throughout electric generator (battery system with dc-ac converter).

5. CONCLUSIONS

Analysis of the data offered by ANRE and ANRGN (Figure 3, Table 1) shows specific consumption and charging structures in conformity with situations existing in urban conditions (2007) as well as the constant changes they imply, such as increased electrical power consumption during summer by using lelectrical powered air-conditioning systems. Presented case studies show high variations of P/Pth ratio. Proposed strategy for choosing and designing a micro-CCHP system takes into consideration adapting as much as possible the P/Pth ratio obtained in the basic thermal engine of the micro-CCHP system with the same P/Pth ratio specific to urban residencies and covering for the thermal necessary through renewabale source (solar energy). The proposed micro-CCHP system (figure 7, figure 8) use fuel cells which works with P/Pth ratios between 0,2...1, depending on the system performance. An IT leading system is an obligatory element for a good functioning of micro-CCHP (monitoring, command, protection, control) and in order to offer the possibility to cover thermal and electrical power peaks.

6. REFERENCES

Hoogers G., (2003). -Fuel cell tehnology Handbook-CRC press-2003.

Kim D.S., Ferreira C.A.I, (2005). Delft University Of Technology, Faculty of Design, Construction and Production, Mechanical Engineering and Marine Technology, 2005;

National Institute of Statistic (2008). Press release no 57 from 19th march 2008 – Electrical Power and Natural Gas Prices for final consumers in the second semester 2007

National Institute of Statistic, (2007). Press Release no. 55/2007 – Electrical Power and Natural Gas Prices for the Consumers on 01.01.2207

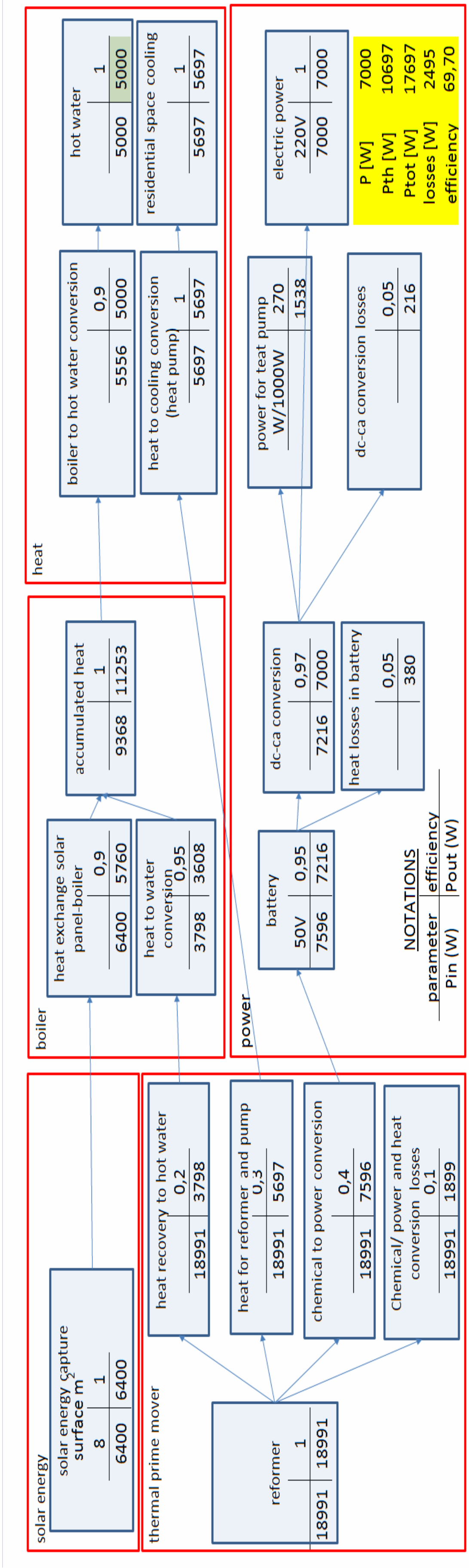
Order no 1353/2007, (2007). – Order regarding regulated prices for keeping the distribution service and proving the prices for regulated natural gas delivery done by S.C ROMGAZ S.A. order no 1353 from 13th December 2006, published in MO no. 1002 from 15th December 2006

WADE (World Alliance of Decentralized Energy), 2002. (www.localpower.org). Guide to decentralized energy technologies.2002.

http://www.anre.ro, http://www.electrica.ro/

Annex 1

The energetically balance for winter



The energetically balance for summer