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## Examination Renewable Energy Sources (4P510)

**Date:** November 7, 2013

**Time:** 14.00 – 17.00 hours

Note: Different lecturers will correct the answers to the various problems for this examination.

**Write down every answer on a different sheet of paper.**

Please write on every sheet of paper you use the following:

1. the problem number;
2. your last name and initials;
3. your identity (student) number;
4. your email;
5. your department;

Should you write down answers to more than one problem on one piece of paper, then the first answer will be corrected and the other answers will be void.

The exam consists of 5 questions. For each question 20 points are available, the maximum score is 100 points.

The use of course books and notes is not allowed.

The use of simple calculators is allowed.

Good luck!

## Problem 1 Renewables in the built environment

- a) As in the name, the '*Trias Energetica*' has 3 successive steps. Explain the steps and comment on the order of the 3 steps.

The 'passive house' philosophy has proven to be effective in the reduction of the energy consumption for heating and hot water with 75%. The main contribution for the reduced energy consumption for heating is based on the 1<sup>st</sup> step of the '*Trias Energetica*'.

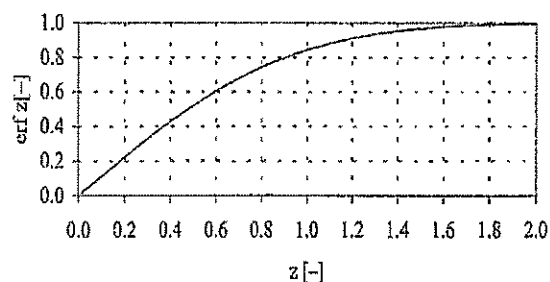
- b) Give the main measures taken related to the 1<sup>st</sup> step of the '*Trias Energetica*' that account for the main reduction of energy consumption for heating.
- c) With the intention to have a *net* energy neutral built environment in 2050, comment with the Strategic and Economic values of BESELF on the 'passive renovation' method.
- d) What are beside '*passive measures*' attractive technologies to come to an energy neutral built environment?  
Name two and comment on the applicability of these technologies for the current building stock.

## Problem 2 Thermal Energy Storage

- a) Make a sketch of a closed sorption heat storage system with its main components, and explain the basic functioning.
- b) What are advantages and disadvantages of paraffines compared to salt hydrates as PCM? Mention at least 3 topics.
- c) Heat is stored in a large ceramic plate with a thickness of 20 cm. The plate is initially heated to 80°C, and is discharged by flowing a large airflow of 30°C over the hot plate. Calculate the time (in seconds) required for the location 5mm into the plate to cool down to 70°C. You may assume the external heat transfer from the block to the air to be infinitely high.

$$\frac{T(t, x) - T_{\infty}}{T_0 - T_{\infty}} = \operatorname{erf}\left[\frac{x}{\sqrt{4\alpha t}}\right] \quad \alpha = \frac{k}{\rho C_p}$$

	ceramic plate
cp (J/kg.K)	900
(W/m.K)	1.5
(kg/m <sup>3</sup> )	2500



### Problem 3 Hydropower

Given the expressions for two dimensionless numbers for turbines with characteristic values for water turbines:

$$\Delta = D \frac{(gZ)^{\frac{1}{4}}}{(\Phi_v)^{\frac{1}{2}}}, \quad \Omega = \omega \frac{\Phi_v^{\frac{1}{2}}}{(gZ)^{\frac{3}{4}}},$$

Dimensionless numbers	$\Delta$	$\Omega$
Pelton (with 6 jets)	5,04	0,26
Francis	2,70	0,53
Propeller	1,14	4,71

Give answer the following questions, **with a brief explanation**.

- a) Generally speaking, for a specific head and flow rate, how much smaller or bigger is a 6-jet Pelton runner, compared to a Propeller runner?

You are asked to select a turbine for an extremely low-head hydropower application as the future Tidal Power Plant Brouwersdam.



Assume for the Brouwersdam project a typical head of 1 meter and a maximum flow rate of 4000 m<sup>3</sup>/s.

- b) What is the theoretical maximum power output of the Brouwersdam Tidal Power Plant?
- c) If there would be no turbines installed and 80 % of the available potential energy would be converted into kinetic energy: Then what would be the flow velocity after conversion?
- d) Given the above information about dimensionless numbers: if the turbine diameter in the Brouwersdam power plant would be restricted to 4 meters, how many turbines would be needed in case Pelton turbines would be applied?
- e) What would be the typical speed (in Revolutions per Minute, RPM) if 4 meter diameter Propeller turbines would be applied?

#### Problem 4 Wind energy

Questions:

- Give the definition of the power coefficient  $C_p$
- Give physical arguments for the limits of the value of  $C_p$
- Give the definition of the capacity factor  $C_f$
- Calculate the yearly electricity production of a wind turbine with a rotor diameter of 100 m, an installed power capacity of 3MW and a capacity factor  $C_f = 0.35$ .
- How can you increase the capacity factor of a wind turbine?  
(give at least two different “solutions” for increasing the capacity factor  $C_f$ )
- Why are modern horizontal axis wind turbine (HAWT’S) equipped with a pitch system?
- Draw a typical North European wind speed Weibull distribution for 10 m height (the meteo standard height), show what is on the x- and y-axis and explain the meaning of this distribution function (absolute numbers are not required, so mainly qualitatively)?
- What can you say about this Weibull distribution at the wind speed at hub height (assume this is 90 m) when the reference surface roughness height is  $z_0 = 0.03$ ?
- How should the chord length (the length of a cross section through the blade) of a lift driven vertical axis wind turbine (VAWT) blade change when moving from a two bladed design to a three bladed design (and all other parameter of the machine stay the same), in order to maintain the same efficiency?
- What should happen with the (optimal) rotational speed in order to maintain the highest efficiency when the size of the VAWT doubles (both the radius and height become twice the original size)?

Formulas that might be helpful:

Weibull probability density function: 
$$f(V) = \frac{k}{V} \left( \frac{V}{a} \right)^k e^{-(V/a)^k}$$

Atmospheric boundary layer equation: 
$$V(h) = V(h_{ref}) \left( \frac{\ln(h/z_0)}{\ln(h_{ref}/z_0)} \right)$$

## Problem 5 Biomass

Biomass can be converted into energy in many ways.

- a) Growing plants capture sunlight and store the energy in chemical bonds.
  1. How is this process called?
  2. Write down its global reaction equation.
- b) Biomass can be converted into ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) via a bio-chemical route.
  1. How is this process called?
  2. Which types of biomass are mainly used as feedstock for this process?
  3. Write down the global reaction equation for this process.
  4. What is the main application of ethanol?
- c) Biomass can also be converted into another alcohol, methanol, by a thermo-chemical process.
  1. Which thermo-chemical process is that?
  2. Describe briefly how this process works.
  3. What type of biomass can be used as feedstock?
  4. Give an advantage of this route compared to the bio-chemical route for alcohol production.
- d) Biomass derived alcohols can be burnt to produce heat and power.
  1. Write down the reaction equation for the combustion of ethanol.
  2. The heating value of ethanol is 26.8 MJ/kg. How much  $\text{CO}_2$  is emitted per unit of energy [ $\text{kg CO}_2/\text{MJ}$ ]?
  3. This is more than for natural gas. Explain why it is beneficial for  $\text{CO}_2$  emissions to use biomass as energy source.