Examination Renewable Energy Sources (4P510)

Date: **November 7, 2012**
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 <u>not</u> allowed.
The use of simple calculators is allowed.

Good luck!

Problem 1   General introduction

For this problem, don't worry if you don't know the exact numbers. It's more about the order of magnitude which counts.

a) What was the average energy use of mankind in kW per capita through history, so ranging from the prehistoric man to the technological man. (4 points)

b) Given the total primary energy usage of 500 EJ in the year 2010, calculate the surface area needed in the Sahara desert to generate our electricity needs using PV or Concentrated Solar Power. Clearly state your assumptions. (4 points)

c) List different methods to reduce CO2 emissions in order of importance. (4 points)

d) What are the 3 main key factors in an energy scenario determining the development of future global energy demand? Explain your answer. (4 points)

e) Explain the extra greenhouse effect. (4 points)

Problem 2   Renewables in the Built Environment

"Improvement of buildings through increased insulation and improved air tightness of the building envelope, can lead to a fast reduction of energy use, though it also will lead to a higher dependency on energy for proper functioning."

a. Comment on the mentioned reduction measures with reference to (some of) the values defined by B.E.S.E.L.F.
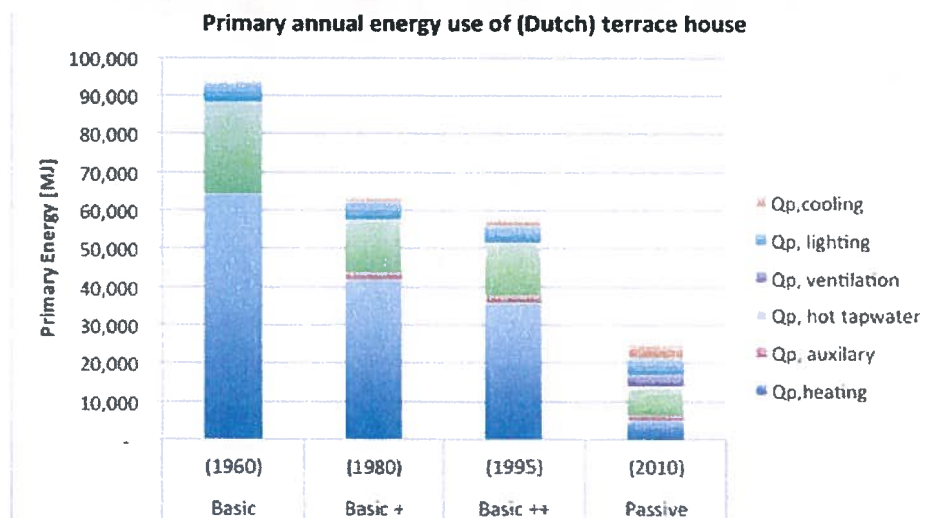
Primary annual energy use of (Dutch) terrace house

b. In the figure above there is a huge difference in the amount of energy needed for heating of a basic house in 1960 and after the renovation in 2010.
   Give the measures (passive and active) that were used to realize this reduction.
c. Explain why insulation of the building envelope for small buildings (dwellings) is of greater importance than for large buildings.
d. For distribution networks the amount of heat transported is $q = f(\Phi_v, T_{sup}, T_{ret})$.
   Give the equation and explain the relation of these variables with the load, the source and the distribution system.

Problem 3   Photovoltaic Conversion

a) Describe which phenomena take place when sunlight strikes on a crystalline silicon solar cell. In detail, answer the following questions and motivate your answers.

   1. Which photons are responsible for carrier generation? (1 point)
   2. Where are the carriers generated within the c-Si solar cell? (1 point)
   3. Where does carrier separation occur? Explain this concept by making use of the band diagram of the p-n junction. (3 points)

b) According to the Shockley-Queisser limit, there is a maximum theoretical efficiency as function of the band gap of the semiconductor when using a single p-n junction.

   1. Explain the presence of the maximum as function of the band gap. (2 points)
   2. According to the above-mentioned limit, the c-Si solar cell should have an efficiency of 25%. The commercial solar cells, however, are characterized by efficiency values well below 25%. Explain in detail the main loss mechanisms occurring in a commercial solar cell. (3 points)

c) Answer the following subquestions:
   1. Draw the diagram of the power-voltage (PV) characteristics of a solar cell and indicate where the maximum power point (P_{mp}) is located. (1 point)
   2. Calculate the P_{mp} for a solar cell characterized by a fill factor (FF) of 0.70, a short circuit current (I_{SC}) of 35 mA/cm^2 and an open circuit voltage (V_{OC}) of 600 mV. (2 points)
   3. Define the standard test conditions and calculate the electrical efficiency of this solar cell.(2 points)

d) Make an accurate sketch of a grid-connected PV system and describe the function of its components. (5points)

Problem 4 Hydropower

Shown is a Turgo turbine. The picture left gives an impression of the flow path from the nozzle, through the turbine rotor. As can be seen, the turbine to some extent looks like the Pelton turbine. Picture right schematically gives the flow path, with velocities V_{in} and V_{out}, relative to a frame of reference that moves with the rotor (peripheral speed V_{periph}).
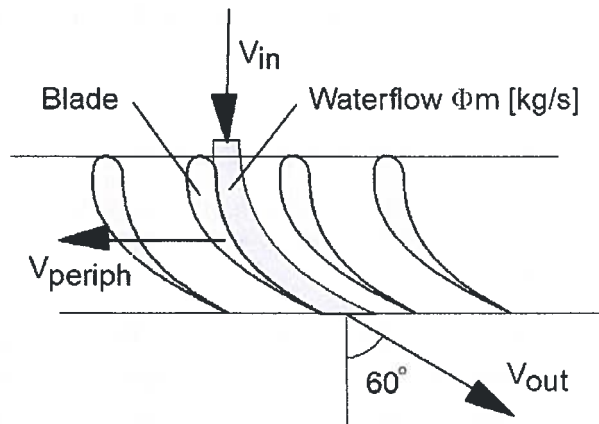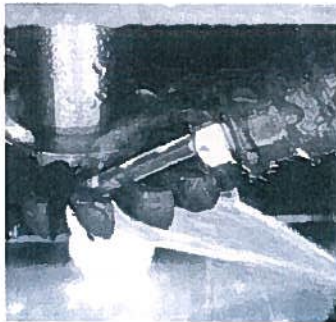
Give the most precise answer 1, 2 or 3, and motivate your answer.

a) The Turgo turbine is an example of what kind of turbine?

1. An impulse turbine;
2. A reaction turbine;
3. Both an impulse and a reaction turbine.

b) Given the velocity diagram (figure right), the runner inlet velocity V_{in} (relative to the moving frame) essentially is, in the absence of fluid friction, in magnitude:

1. equal to the outlet velocity V_{out};
2. Higher than the outlet velocity V_{out};
3. Lower than the outlet velocity V_{out}.

c) On the basis of the velocity diagram, the circumferential impulse F [N] of the water jet, driving the runner is equal to:

1. Φ_m [(sin 60) V_{out} - V_{in}];
2. Φ_m (tan 60) V_{out};
3. Φ_m (sin 60) V_{out}.

d) The velocity diagram (inlet and outlet velocities relative to the moving frame of reference), indicates that the turbine operates:

1. At adequate rotational speed;
2. Rotates much too slow;
3. Rotates much too fast.

e) Given the size of the turbine runner (relative to the jet diameter) and the velocity diagram, the Turgo Turbine is especially suited for applications, characterised by:

1. High dimensionless speed Ω and large dimensionless diameter Δ
2. Low dimensionless speed Ω and large dimensionless diameter Δ
3. Low dimensionless speed Ω and small dimensionless diameter Δ

Problem 5   Hydrogen Technology

Hydrogen plays already an important role in the production of clean transportation fuels. It might become an efficient energy carrier in the future facilitating a shift to a sustainable low carbon society.

a) Name at least three fossil resources for the production of H_2?
Which is predominant and what process is used to produce hydrogen from this feedstock.
Why is this process not regarded as a sustainable production process for hydrogen?

b) Mention at least three other ways to make H_2 in a (more) sustainable manner and discuss briefly the main aspects.

Fuel cells are efficient devices for the conversion of chemical energy in electricity.

c) Give a schematic representation of a fuel cell and give the two electrochemical half reactions occurring in a hydrogen fuel cell (indicate: cathode, anode, electron flow, electrolyte, reactants (fuel, air), products).

d) What is the difference between a proton exchange membrane fuel cell and a solid oxide fuel cell in terms of the electrolyte? What does this mean for the operating temperatures of the two types of cells?
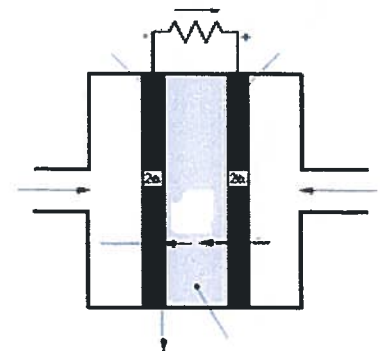
Instead of hydrogen, methanol (CH_3OH) is another type of fuel which can be used to drive a direct methanol fuel cell. The overall reaction in this fuel cell is:

$$CH_3OH + 3/2\ O_2 \rightarrow 2\ H_2O + CO_2$$
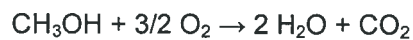
Given the following Gibbs free and standard enthalpies of formation:

Compound	ΔG_f° (kJ/mol)	ΔH_f° (kJ/mol)
CH_3OH (l)	-163	-238
H_2O (l)	-237	-286
CO_2 (g)	-394	-394

Note the following:
- Gibbs free energies and standard enthalpies of formation of the elements are zero;
- Faraday's constant, F = 96485 C/mol.

e) Compute the Gibbs free and standard enthalpy changes for the overall oxidation of methanol.

f) Compute the maximum efficiency of a direct methanol fuel cell.

g) Calculate the open circuit potential.