



AQUAculture infrastructures for EXCELlence  
in European fish research towards 2020 —  
AQUAEXCEL2020

## **D5.7: Final model on water quality and water temperature for experimental facilities (M51)**

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# Executive Summary

## Objectives

The purpose of this document is to describe the functionality and technical implementation of the water quality model and the heat balance model.

This water quality model is one of the main components in the AQUAEXCEL<sup>2020</sup> virtual laboratory, which will be developed in WP5: "Virtual laboratories and modelling tools for designing experiments in aquaculture research facilities".

The main components of the Virtual Laboratory are:

- Task 5.1; Growth, nutrition and waste production models for different fish species
- Task 5.2; Water quality and water treatment modelling
- Task 5.3; Modelling of hydrodynamic flow fields in tanks and cages

The objective of this sub-model is to develop a generic tool that enables a user of a research facility to predict the water quality in an existing research infrastructure (RI) prior to the start of an experiment and to (re-)design a system which results in the desired water quality for the experiment envisioned. The tools will enable teaching of TNA users, RI technicians and others involved in the principles of water quality control in fish culture units. The model uses input on waste production from task 5.1 as a starting point. The separate, thermal model will enable a user of an RI to predict requirements for heating/cooling and manage water temperature.

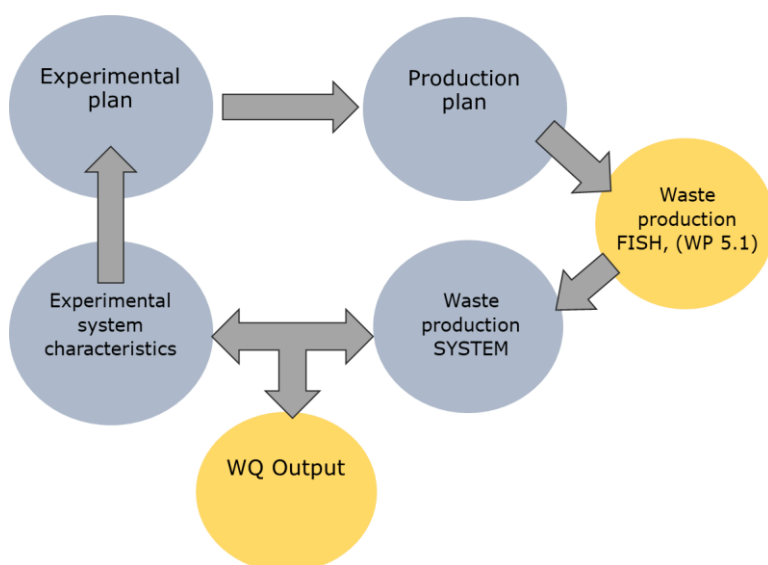


Figure 1: Format of the design of the water quality model

## Rationale

One of the main research activities in AQUAEXCEL<sup>2020</sup> is to develop a virtual laboratory system that enables virtual experiments in aquaculture research facilities. This system will feature a framework that allows the integration of mathematical models of different subsystems in common simulations, replicating the system operation of research laboratories.

## Main Results

The water quality model has been developed, and it is shown that this model component can be integrated with the other main components, coming from task 5.1. The model describes flow schemes and experimental set-ups, and covers relevant conditions such as fish load/feed load, system type, and temperature. The model requires input from an experimental plan, waste production by the fish and system characteristics (**Figure 5.1**), and has as output the water quality in the fish tank, in the form of O<sub>2</sub>, CO<sub>2</sub>, ammonia, solids and nitrate.

The thermal model predicts requirements for heating/cooling to manage the water temperature in the fish tank. It requires input for the local external environment (warmest and coldest day), housing characteristics, and the fish culture system. The main output is the heating that is required for the water and air. The model describes the energy balance the warmest and coldest day of the year. All intermediate weather conditions are then assumed to be covered by the model.

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And in close collaboration with partners from task 5.1 (led by HCMR) and involved staff from Sintef Ocean.

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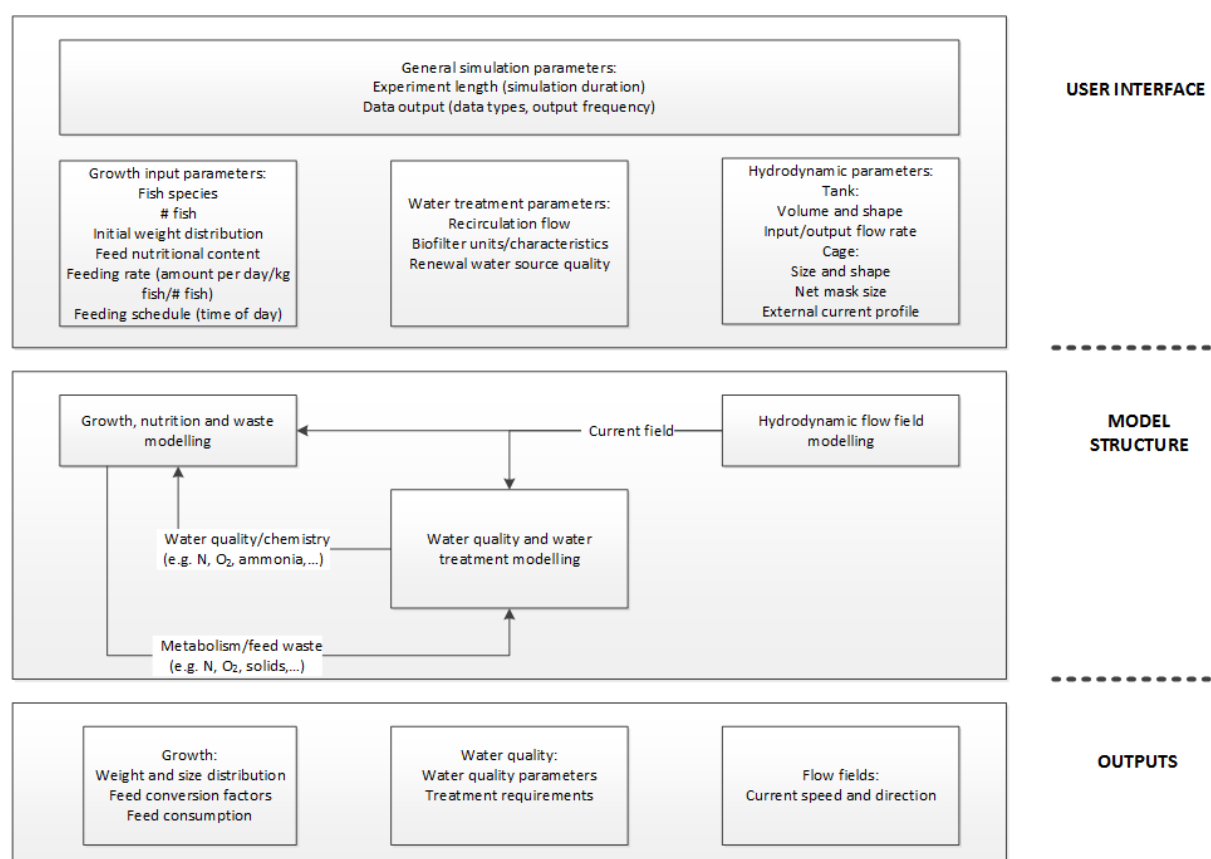
# 1. BACKGROUND

This document is part of the AQUAEXCEL<sup>2020</sup>, WP5/Joint Research Activity 1 – Virtual laboratories and modelling tools for designing experiments in aquaculture research facilities.

Experiments with fish usually involve extensive use of laboratory facilities and run for long periods of time. Both from an ethical perspective (3R's) and from a cost perspective, tools for design and planning of experiments are increasingly important. In aquaculture research as well as other domains, numerical models are increasingly used preparatory to the actual experiments.

One of the main research activities in AQUAEXCEL<sup>2020</sup> is to develop a virtual laboratory system that enables virtual experiments in aquaculture research facilities. This system will feature a framework (Bjørnson et al., 2016 and Bjørnson et al., 2019) that allows the integration of mathematical models of different subsystems in common simulations, replicating the system operation of research laboratories. The overall system architecture is shown in **Figure 2**.

This document describes the technical implementation and functionality of the water quality model and of the energy balance model.



**Figure 2: Virtual laboratory system architecture**

The objective of this task is to develop a generic tool (model) that enables a user of a research facility to:

- (1) predict the water quality in an existing research infrastructure prior to the start of an experiment and

- (2) to (re-)design a system which results in the desired water quality for the experiment envisioned.

The model on water quality will cover relevant conditions such as load of fish/feed, seawater/freshwater, system type, life stage of the fish, and treatment systems.

The second model, the thermal model, will enable a user of an RI to predict requirements for heating/cooling and manage water temperature.

The tools will enable teaching of TNA users, RI-technicians and others involved in the principles of water quality control in fish culture units.

This document describes the final version of the water quality model and heat balance model. The earlier report D5.3 described the initial model version of the water quality model. For completeness, this report repeats the parts of D5.3 that are still relevant, and adds descriptions of new and modified functionality and parameters. In addition, the heat balance model was not reported in D5.3, but is reported in the final version in the present report D5.7.

## **2. WATER QUALITY MODEL**

### **2.1 Water quality model design**

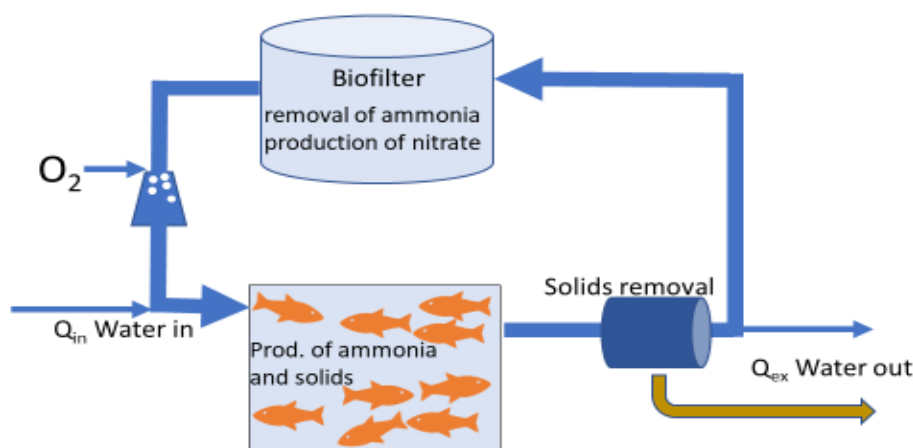
The water quality model (**Figure 3**) assumes a constant production by fish during the day and a constant and instant ammonia removal by water exchange and bio-filtration; there is no temporarily accumulation of ammonia in the water. Peaks in ammonia production could be introduced in the model as a function of feed load by hourly instead of daily iterations and introducing hourly feed loads.

As long as removal capacity exceeds production, the resulting ammonia concentration in the water remains zero. In reality this is not true; ammonia is continuously produced and removed, therefore the actual ammonia concentration in the water is never exactly zero. The model uses time slots of 1 h and can therefore not monitor the continuous production and removal within hours.

Nitrate production is assumed to equal ammonia removal by biofiltration and denitrification is assumed to be absent. The accumulation of the intermediate product nitrite in nitrification process is ignored.

Ammonia (or nitrate) addition to the water to create ammonia treatments at different levels for the purpose of water quality experiments, is another source of ammonia in the system that is currently not considered in the model. Ammonia in the model equals  $\text{NH}_4^+ + \text{NH}_3$ . By including temperature and pH in the model (either as input or as output), the molar fraction of  $\text{NH}_3$  could be calculated and the  $\text{NH}_3$  concentration included as model output.

## Water quality model



In a RAS, the water circulates between the fish tanks and the bio-filter, with a refreshment and flows between the main components

**Figure 3: The design of the model, with the various inputs leading to the output in the form of the water quality for ammonia, nitrate, O<sub>2</sub>, CO<sub>2</sub> and solids.**

## 2.2 Water quality model Input

The water quality model will enable a user of an RI to predict the water quality in the fish tanks. The model uses as input the hourly feed intake, growth and waste production from the growth nutrition and waste modelling (see **Figure 2** for an overview).

Therefore, the model requires firstly input from the user for the fish production plan and the related waste production (**Annex 2.1**):

### Fish production plan:

- Fish species
- Initial body weight (BW<sub>i</sub>) of the fish (g)
- Initial number of fish (#)
- Mortality (%/d)
- SGR (%BW/d)
- Feeding level (%BW/d)

The number of fish on any given hour is calculated from the initial number of fish and the predicted mortality rate (%/d) (model input).

The individual hourly fish weight (g) over time (growth, growth curve) is calculated from the feed conversion ratio (FCR) based on the feeding level (%BW/d) and the specific growth rate (% BW/d).

The feed intake per fish per hour is calculated from the initial individual bodyweight (g) on that day and the feeding rate (%BW/d) (model input).

The hourly feed load is calculated from the amount of feed per fish for a given day (g/d) \* number of fish.

### Waste production:

- Solids (TSS) production fish (= Faecal dry matter) (g/h)

- Oxygen (O<sub>2</sub>) consumption (g/h)
- Carbon dioxide (CO<sub>2</sub>) production (g/h)
- Total Ammonia Nitrogen (TAN) production (= Non Faecal Loss-N) (g/h)

Waste production by fish depends on many factors, such as fish species, age, feeding level and environmental factors such as temperature, pH salinity etc. Hourly waste production in the water quality module is calculated for total suspended solids, total ammonia nitrogen, oxygen and carbon dioxide.

Total suspended solids production (gTSS/h) is calculated from the solids production per kg feed (model input task 5.1 where dietary composition and digestibility of the ingredients is taken into account) and the hourly feed load.

TAN production (mg TAN/h) is calculated from the TAN production per kg feed (model input) and the hourly feed load. The amount of nitrogen in the faecal loss is neglected.

Oxygen consumption (mgO<sub>2</sub>/h) is calculated from the oxygen consumption per kg feed (model input) and the hourly feed load.

Carbon dioxide production (mg CO<sub>2</sub>/h) is calculated from the oxygen consumption per kg feed (model input) and the hourly feed load using a respiratory quotient (RQ = gO<sub>2</sub>/gCO<sub>2</sub>) (RQ is model input).

Secondly, the model requires input from the user on the experimental system used.

#### Water quality conditions:

- Water temperature (°C)
- Water pH (-)
- Oxygen concentration fish tank in (mg/L)
- Ammonia concentration system renewal water (mg/L)
- Nitrate concentration system renewal water (mg/L)
- Solids concentration system renewal water (mg/L)
- Total Inorganic Carbon concentration (TIC)

The ammonia concentration in the water at any given moment equals the total amount of ammonia present in the system at that moment divided by the total water volume. The total amount of ammonia present in the system is calculated using the following mass balance:

Total amount of ammonia present in the system = Production of ammonia by the fish + Ammonia already present in the system - Ammonia removal by water exchange - Ammonia removal by nitrification. The calculation of each component of the mass balance is given below:

Production of ammonia (TAN) by the fish:

TAN production (mg TAN/h) is calculated from the TAN production per kg feed (model input) and the hourly feed load. The amount of nitrogen in the faecal loss is neglected.

Daily ammonia accumulation:

The daily ammonia accumulation equals the difference between ammonia production and ammonia removal on a given day. The total ammonia present in the system on a given day can also be calculated as the sum of the total ammonia present in the system on the previous day and the ammonia accumulation on the given day.

Ammonia removal by water exchange:

Part of the total amount of ammonia present in the system that can be removed will be removed by water exchange. This water exchange takes place after the biofilter where the ammonia concentration is lowest. This fraction is calculated as follows: Water exchange volume (L/h) \* (TAN concentration biofilter outlet water (mg/L) – TAN concentration in new water supply (mg/L)). The system water exchange rate (L/d) is user input.



-Ammonia removal by nitrification:

The part of the total amount of ammonia present in the system that is available for nitrification equals *Production of ammonia by the fish + Ammonia already present in the system - Ammonia removal by water exchange*. The amount of TAN that is nitrified depends on the nitrification capacity (g N/d) of the system. The nitrification capacity of the biofilter is calculated with an equation for the nitrification rate (g TAN removal per m<sup>2</sup> per day). The ammonia removal rate depends on the TAN concentration the biofilm in the biofilter is exposed to. Other factors affecting nitrification are the temperature (correction factor in the model) and pH (can be incorporated in Aquaexcel3.0). The biofilter area available is calculated from the biofilter volume (user input) and the specific surface area of the biofilter (user input).

There are two scenarios with respect to nitrification capacity:

- nitrification capacity < amount of TAN available for nitrification
- nitrification capacity > amount of TAN available for nitrification

Under the first scenario, the amount of TAN that is nitrified = nitrification capacity.

Under the second scenario, the amount of TAN that is nitrified = the amount of ammonia that is available for nitrification.

Total ammonia nitrogen inlet and outlet concentration of the fish tank (mg TAN/L):

The initial TAN concentration (mg TAN/L) in the fish tank inlet is 0 mg/L (user input). The TAN concentration in the tank outlet is calculated from the water flow (L/h) across the fish tank multiplied with the TAN concentration (mg TAN/L) in the tank inlet plus the TAN production (mg TAN/h) in the fish tank. This amount of TAN per hour (mg TAN/h) is divided by the water flow (L/h) giving the TAN concentration (mg TAN/L) in the fish tank outlet.

#### System characteristics:

- Total water volume fish tanks (L)
- Total water volume in the remaining part of the system (L)
- Recirculation water flow rate (L/day)
- System water exchange flow rate (L/day)
- Total biofilter volume (m<sup>3</sup>)
- Filling percentage (%)
- Specific Surface Area (SSA) biofilter media (m<sup>2</sup>/m<sup>3</sup>)
- Removal efficiency drum filter (%)
- Gas:Liquid ratio biofilter (GLR)
- Acid-base equilibria carbonate system (K0, K1, K2)

#### Initial model values:

- Oxygen concentration fish tank in (mg/L)
- Total ammonia nitrogen concentration fish tank in (mg/L)
- Solids concentration fish tank in (mg/L)
- Total inorganic carbon concentration fish tank in (mg CO<sub>2</sub>/L)

## **2.3 Water quality model calculations**

The model uses the data input data in subchapter 2.1 to calculates for the experiment the following production plan parameters (**Annex 2.2**):

Calculated production plan parameters:

- Feed conversion ratio (FCR) (kg feed/kg growth)
- Water volume fish tank (L)

- Total flow rate (recirculation flow + water renewal flow) (L/d)
- Biofilter water volume (L)
- Biofilter media volume (L)
- Biofilter surface area (m<sup>2</sup>)
- Water volume fish tank + hourly water flow (L)
- Water volume biofilter + hourly water flow (L)
- Total water volume system (L)
- Nitrification rate correction factor

Calculated production parameters:

- Stocking density (kg/m<sup>3</sup>)
- Max. realised feed load (g/d)
- Max. realised feed load on biofilter (kg/m<sup>3</sup>)

## **2.4 Water quality model output**

The water quality model calculates the water quality for the fish tank out (oxygen, ammonia, nitrate, solids and carbon dioxide) per hour (**Figure 4**). Number of fish present, individual fish weight, feed per fish and total feed consumed by all fish (all per hour) are calculated for the experimental period. Other hourly values that are calculated include oxygen supply, oxygen consumption, and nitrification rate, are presented in **Annex 2.3**.

Hourly water quality model output:

- No of fish (# fish)
- Individual body weight (g)
- Feed per fish (g/dt)
- Total fed load (g/dt)

Water quality fish tank:

Oxygen:

- Oxygen fish tank in (mg/L)
- Oxygen fish tank out (mg/L)

Ammonia and Nitrate:

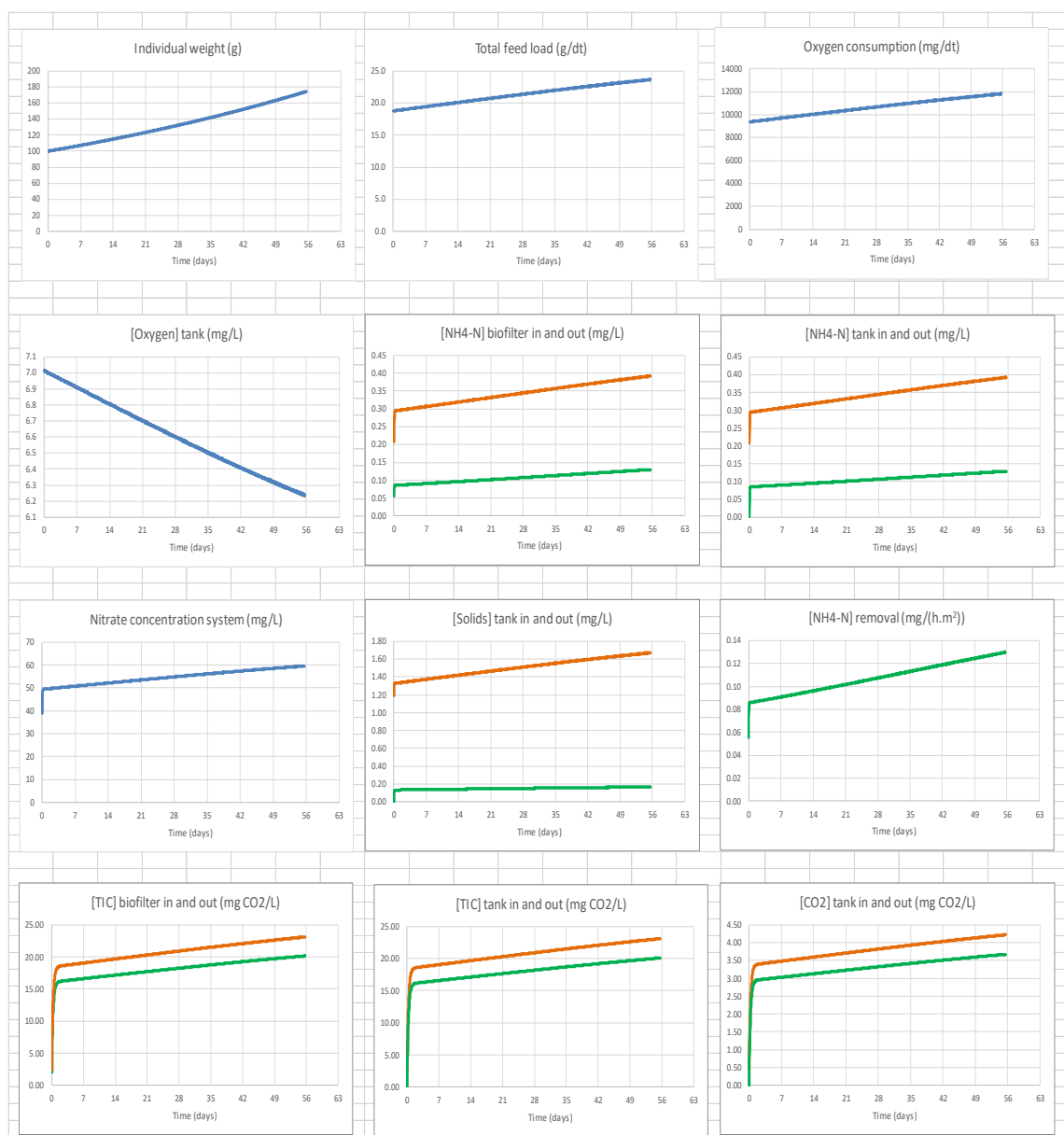
- Ammonia fish tank in (mg/L)
- Ammonia fish tank out (mg/L)
- Nitrate concentration system (mg/L)

Solids:

- Solids concentration fish tank in (mg/L)
- Solids concentration fish tank out (mg/L)

Carbon dioxide:

- Carbon dioxide concentration fish tank in (mg/L)
- Carbon dioxide concentration fish out (mg/L)



**Figure 4: Water quality simulation for the fish tank inlet and outlet for oxygen (for a controlled inlet oxygen concentration of 8.5 mg/L), total ammonia, solids, carbon dioxide and nitrate (only one hourly concentration as we assume no nitrate is produced in the fish tanks). Fish are growing in this example from approximately 160 g to 180 g in an experimental period of 56 days.**

## 2.5 Water quality model validation

Initial development of the model was done by using a set of realistic data coming from the experimental fish facilities of Wageningen University and Research. These input data for fish and experimental set-up parameters resulted in realistic output data for water quality. Validation of the water quality model will be done after integration of the sub-model in the VL when the sub-models function in accordance with each other. Validation of the model will be achieved by using data from an experiment that was done in the experimental facilities of Wageningen University and Research. Data and values coming from this experiment that are needed as input for the model on the fish production plan, waste production, water quality conditions, system characteristics and the initial model values are available. Data from the water quality parameters that are the output of the model are also available from daily

measurements of the water quality during the experiment. The predicted water quality based on the input from the experiment, will be compared with the actual measured water quality levels. Validation is considered successful when the predicted water quality level is equal to the actual measured water quality levels.

### 3. HEAT BALANCE MODEL

#### 3.1 Heat balance model design

The second model, the thermal model, will enable a user of an RI to predict requirements for heating/cooling and manage water temperature. The model covers the fish load and feed load, climate and insulation. Specific attention is being paid to interactions in the model regarding evaporation, cooling and degassing. The model uses input from the environment, the housing characteristics, and the fish culture system. The output is a prediction on the heating that is required for the water, and heating that is required for the air (**Figure 5**). The model describes the energy balance on a very warm and very cold day. All the intermediate temperatures will be covered by the installed installation in the particular housing characteristics.

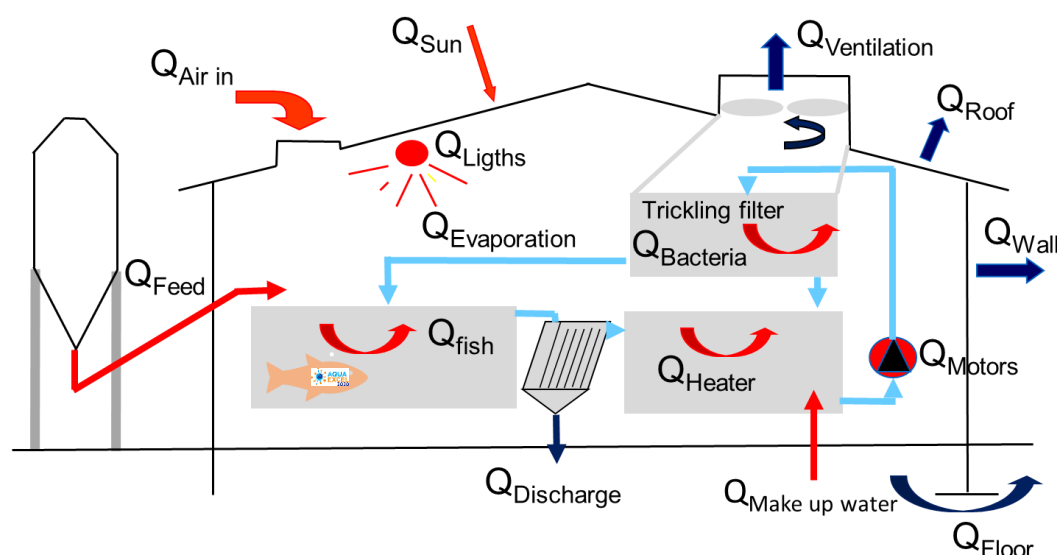


Figure 5: The design of the thermal model, with the various inputs. The total heat balance is made up of energy flows going into the chain ( $Q_{air}$ ,  $Q_{feed}$ ,  $Q_{sun}$ ,  $Q_{lights}$ ,  $Q_{motors}$ ,  $Q_{make\ up\ water}$ ,  $Q_{heater}$ ,  $Q_{fish}$ ,  $Q_{bacteria}$ ) and energy flows that go out of the chain ( $Q_{wall}$ ,  $Q_{roof}$ ,  $Q_{ventilation}$ ,  $Q_{discharge}$ ,  $Q_{floor}$ ). From this heat balance, the output in the form of the required heating for water and air on the warmest and coldest day of the year is calculated.

#### 3.2 Heat balance model input

The input of the thermal model comes from various sources, summarized in the external environment, the housing characteristics, and the fish culture system. The list below shows all the input parameters that were used in the development of the model. They are based on:

- fish
- fish feed composition
- the water refreshment
- fish tank characteristics
- trickling filter
- solids removal unit characteristics
- pumps and pipes

- design boundaries
- housing characteristics
- outside building temperatures
- some default values.

All input variables are shown in **Annex 2**. In addition to the input parameters, there are some design requirements that are used as input. These are temperature boundaries for the water in the tanks, temperature boundaries for the air inside the room where the fish are being held, and relative humidity of the air inside, and the temperature of the air going into the trickling filter (**Annex 2**).

### **3.3 HEAT BALANCE MODEL CALCULATIONS**

The model uses the various inputs for a series of calculations that include 24 h weather data from a very cold day (4 February 2012), and 24 h weather data from a very warm day (2 July 2015) in the Netherlands. The model assumes that when the combination of housing characteristics and fish culture system characteristics at weather conditions for a very warm day and a very cold day can maintain heating and cooling conditions in the RI, then all the intermediate weather conditions are also covered. These weather conditions have the following inputs:

- Date
- Time
- Temp (°C)
- Relative Humidity (RH) (%)
- Q\_sun (J/cm<sup>2</sup>)
- Q\_sun (W/m<sup>2</sup>)

The next steps in the model calculations are the intermediate calculations that serve as an interface between the input variables and the intermediate output parameters. These calculations include the Mollier diagram (which describes the relation between air humidity and air temperature) showing the effect of heating, cooling, evaporation and ventilation.

### **3.4 HEAT BALANCE MODEL OUTPUT**

The intermediate output forms the last aspect in the chain of calculations to lead to the final output of heat requirement for the water and air in the room. The intermediate output is formed by the heat loss from various parts of the system and building, and energy flows (heat production) from the fish:

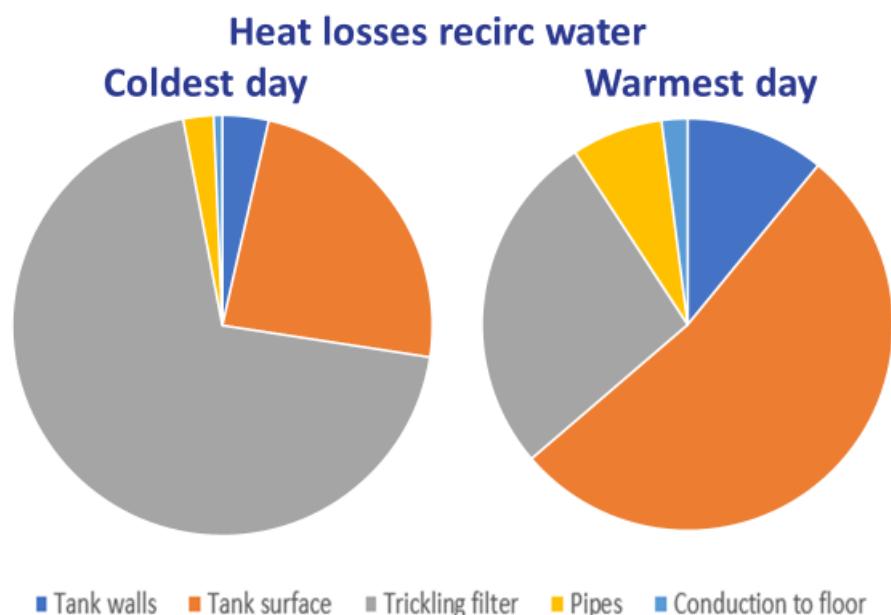
- heat loss from the tank walls, tank surface, trickling filter, pipes, conduction under the tanks, heat pumps to water and tanks;
- heat loss from the building walls, roof, floor, ventilation;
- energy intake fish, energy faeces, energy retention fish, heat production fish.

The final output of the model describes the total heating/cooling that is required for the water, and the total extra heating/cooling that is required for the air in the room where the fish culture system is located in.

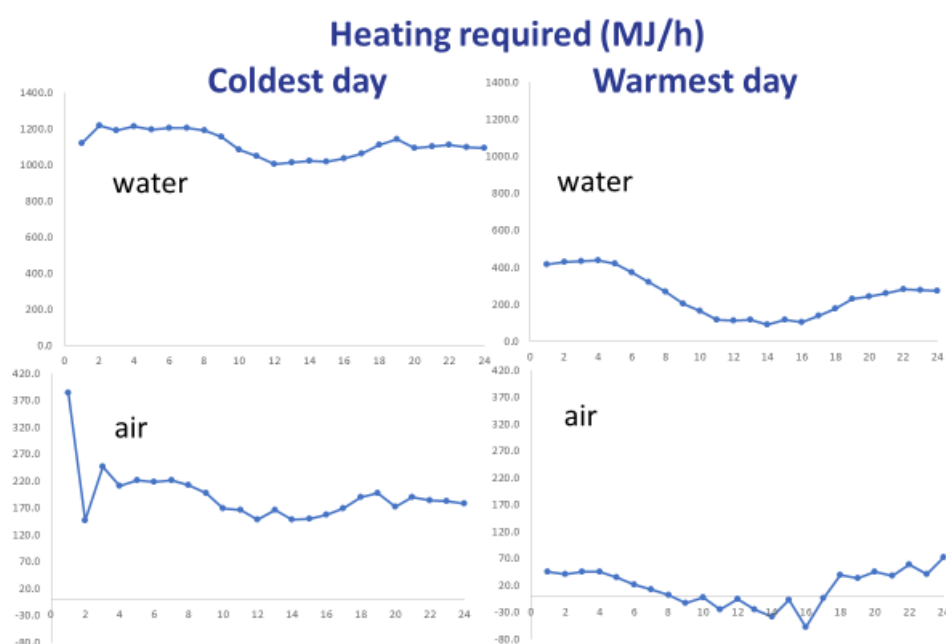
The model predicts the required heating needed for the warmest day that was used for the calculations, and for the coldest day that was used. This means that there are two sets of outputs, and two sets of corresponding figures. **Figure 6** shows the heat losses from the recirculation water on the cold day and the warm day in the model. It shows that on the coldest day, most heat is lost via the trickling filter (around 75%), followed by the tank surface (around 25%). On the warmest day, most heat is lost via the tank surface (around 50%), followed by



the trickling filter (around 25%). **Figure 7** shows the heating that is required for the water and for the air on the coldest and on the warmest day. Some cooling of the air is needed during the day of the warmest day modelled.



**Figure 6: Heat losses from the recirculation water.**



**Figure 7: Heating required for the water and the air.**

## 4. INTEGRATION INTO THE VIRTUAL LABORATORY

The final version of the water quality model has been developed and we have successfully been able to integrate the model into the Virtual Laboratory in Bjørnson et al. (2019).

The water quality model is one of the main components in the AQUAEXCEL<sup>2020</sup> virtual laboratory, which has been developed in WP5: "Virtual laboratories and modelling tools for designing experiments in aquaculture research facilities".

The main connected components of the Virtual Laboratory are:

- Growth, nutrition and waste production models for different fish species
- Water quality and water treatment modelling
- Modelling of hydrodynamic flow fields in tanks and cages

The prototype version of the virtual lab showed the integration of the three sub models. In the remaining time of the project, the integration of the models in the VL will be further optimized and validated with data from actual experiments that were carried out. When the models are successfully integrated, there will be one set of input parameters, and one set of output parameters for the VL.

The heat balance model will be a separate tool in the VL, with its own input and output parameters.

## References

Bjørnson F.O., Føre M., Senneset G., Omholt Alver M. D5.1 Model development guidelines, AQUAEXCEL<sup>2020</sup> Report, 2016.

Abbink W., Eding, E., Schram E. D5.3 First prototype model on water quality and water temperature for experimental facilities, AQUAEXCEL<sup>2020</sup> Report, 2018.

Bjørnson F.O., Kelasidi E., Føre M., Senneset G., Omholt Alver M. D5.5 Virtual laboratory version 1, AQUAEXCEL<sup>2020</sup> Report, 2019.

## Document information

<b>EU Project N°</b>	652831	<b>Acronym</b>	AQUAEXCEL <sup>2020</sup>
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<b>Deliverable</b>	<b>N°</b>	D5.7	<b>Title</b>	Final model on water quality and water temperature for experimental facilities
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<b>Dissemination level</b>	X	<b>PU Public, fully open, e.g. web</b>		
		<b>CO Confidential, restricted under conditions set out in Model Grant Agreement</b>		
		<b>CI Classified, information as referred to in Commission Decision 2001/844/EC.</b>		

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Version log			
Issue Date	Revision N°	Author	Change
23/12/2019	1		First version
27.12.2019	2		First review by WP leader

## Annex 1: Check list

	Check list		Comments
BEFORE	I have checked the due date and have planned completion in due time	X	<i>Please inform Management Team of any foreseen delays</i>
	The title corresponds to the title in the DOW	X	<i>If not please inform the Management Team with justification</i>
	The dissemination level corresponds to that indicated in the DOW	X	
	The contributors (authors) correspond to those indicated in the DOW	X	
	The Table of Contents has been validated with the Activity Leader	X	<i>Please validate the Table of Content with your Activity Leader before drafting the deliverable</i>
	I am using the AQUAEXCEL <sup>2020</sup> deliverable template (title page, styles etc)	X	<i>Available in "Useful Documents" on the collaborative workspace</i>
<b>The draft is ready</b>			
AFTER	I have written a good summary at the beginning of the Deliverable	X	<i>A 1-2 pages maximum summary is mandatory (not formal but really informative on the content of the Deliverable)</i>
	The deliverable has been reviewed by all contributors (authors)	X	<i>Make sure all contributors have reviewed and approved the final version of the deliverable. You should leave sufficient time for this validation.</i>
	I have done a spell check and had the English verified	X	
	I have sent the final version to the WP Leader, to the 2 <sup>nd</sup> Reviewer and to the Project coordinator (cc to the project manager) for approval	X	<i>Send the final draft to your WPLLeader, the 2<sup>nd</sup> Reviewer and the coordinator with cc to the project manager on the 1<sup>st</sup> day of the due month and leave 2 weeks for feedback. Inform the reviewers of the changes (if any) you have made to address their comments. Once validated by the 2 reviewers and the coordinator, send the final version to the Project Manager who will then submit it to the EC.</i>

## Annex 2: Input & output parameters for water quality model

### Annex 2.1: Input variables and design requirements for water quality model

#### Input variables

Input Production plan	Unit
Fish species	
Initial bodyweight fish (BW)	g
Initial number of fish	
Mortality	%/d
SGR	%/kg BW/d
Feeding level	%/kg BW/d
Solids production	g solids/kg voer
Oxygen consumption	g/kg feed
Respiration coefficient (RQ)	
Ammonia production	g N/kg feed

#### Input SYSTEM

Input SYSTEM	Unit
Temp water	oC
[oxygen] tank in	(mg/L)
Volume total tank (fish+water)	L
Volume water remaining system	L
Recirculation flow rate Q <sub>r</sub>	L/d
System exchange flow rate Q <sub>ex</sub>	L/d
Total biofilter volume	L
Filling percentage	%
Specific surface area	m <sup>2</sup> /m <sup>3</sup>
Ammonia conc. System renewal water	(mg N/L)
Nitrate conc. System renewal water	(mg N/L)
Removal efficiency DrumFilter (%DF)	%
Solids conc. System renewal water	(mg solids/L)
TIC conc. System renewal water	(mg CO <sub>2</sub> /L)
Gas:Liquid ratio BF	(-)
pH	(-)
K <sub>0</sub>	(-)
K <sub>1</sub>	(-)
K <sub>2</sub>	(-)

#### Starting values

[oxygen] tank start	(mg/L)
[NH <sub>3</sub> ] tank in	(mg/L)
[Solids] tank in	(mg/L)
TIC tank in	(mg CO <sub>2</sub> /L)



## Annex 2.2: Water quality model (production plan) output

Calculated production plan	Unit
FCR	kg/kg
Water volume tank	L
Total flow rate $Q_r + Q_{ex}$	L/d
Biofilter water volume	L
Biofilter media volume	L
Biofilter area	m <sup>2</sup>
$V_{bf} + dtQ_r$	L
$V_t + dtQ_t$	L
Volume water total system	L
[Oxygen] at saturation	mg/L
Nitrification rate cor fact T water	

### Calculated production parameters

Stocking density	kg/m <sup>3</sup>
Max. feed load	g/d
Max feed load to BF	kg/m <sup>3</sup>

## Annex 2.3: Water quality model (hourly) output.

Time (hr)	Hours
Time (day)	Days
dt (day)	dt
# Fish	no_fish
Production	
Individual weight (g)	W
Feed per fish (g/dt)	Feed
Total feed load (g/dt)	Feed_total
Oxygen (toegevoegd O <sub>2</sub> biofilter?)	
Oxygen supply (g/dt)	O <sub>2</sub> _supply
[Oxygen] tank in (mg/L)	O <sub>2</sub> _tank_in
Oxygen consumption (mg/dt)	O <sub>2</sub> _fish
[Oxygen] tank (mg/L)	O <sub>2</sub> _tank
[Oxygen] tank out (mg/L)	O <sub>2</sub> _tank_out
Ammonia and nitrate	
[Ammonia] tank in (mg/L)	NH <sub>3</sub> _tank_in
Ammonia production Fish (mg N/dt)	NH <sub>3</sub> _fish
[Ammonia] tank out (mg/L)	NH <sub>3</sub> _tank_out
[Ammonia] BF in (mg/L)	NH <sub>3</sub> _BF_in
Max. nitrification rate (g N/m <sup>2</sup> /d)	Max_NO <sub>3</sub> _rate
Nitrification capacity (mg N/dt)	NO <sub>3</sub> _cap

Ammonia load BF (mg N/dt)	NH3_load_BF
Ammonia removal BF (mg N/dt)	NH3_removal_BF
[Ammonia] BF out (mg/L)	NH3_BF_out
Ammonia removal exchange water (mg N/dt)	NH3_removal_ex
Nitrate production (mg N/dt)	NO3_prod
Nitrate concentration system (mg/L)	NO3_conc
Ammonium removal rate (mg/dt/m2)	
Solids	
[Solids] tank in (mg/L)	Solids_tank_in
Solids production (mg/dt)	Solids_prod
[Solids] tank out (mg/L)	Solids_tank_out
Solids removal drum filter (mg/dt)	Solids_removal_drum
[Solids] drum filter out (mg/L)	Solids_drum_out
Solids removal exchange water (mg solids/dt)	Solids_removal_ex
Carbon dioxide	
[TIC] tank in (mg CO2/L)	TIC_tank_in
[CO2] tank in (mg CO2/L)	CO2_tank_in
CO2 production Fish (mg/dt)	CO2_fish
[TIC] tank out (mg CO2/L)	TIC_tank_out
[CO2] tank out (mg CO2/L)	CO2_tank_out
[TIC] BF in (mg CO2/L)	TIC_BF_in
TIC load BF (mg CO2/dt)	TIC_load_BF
[CO2] BF in (mg/L)	CO2_BF_in
[CO2] removal BF (mg/L)	[CO2]_removal_BF
CO2 removal BF (mg/dt)	CO2_removal_BF
[TIC] BF out (mg/L)	TIC_BF_out
TIC removal exchange water (mg CO2/dt)	TIC_removal_ex

## Annex 3: input and output parameters for heat balance model

### Annex 3.1: Input variables and design requirements for heat balance model

Input variables	Unit
<b>Housing characteristics</b>	
House_length	(m)
House_width	(m)
House_height_walls	(m)
House_height_top	(m)
House_window_area	(m)
U-value_walls	(W/(m2.K))
U-value_windows	(W/(m2.K))

U-value_roof	(W/(m <sup>2</sup> .K))
U-value_floor	(W/(m <sup>2</sup> .K))

**Fish tank characteristics**

Tank_shape	
Tank_number	
Tank_diameter	m
Tank_length	m
Tank_width	m
Tank_height	m
U-value_walls_tank	(W/(m <sup>2</sup> .K))

**Trickling filter characteristics**

Trickling_number	
Trickling_length	m
Trickling_width	m
Trickling_height	m
Trickling_water_flow	m <sup>3</sup> /h
U-value_walls_trickling	(W/(m <sup>2</sup> .K))

**Solids removal unit characteristics**

Solids_number	
Solids_length	m
Solids_width	m
Solids_height	m

**Pumps**

Pump_number	
Pump_flow_rate	m <sup>3</sup> /h
Pump_power	kW
Pump_efficiency	-

**Pipes**

Pipes_total_length_type1	m
Pipes_diameter_type1	cm
Pipes_total_length_type2	m
Pipes_diameter_type2	cm
Pipes_total_length_type3	m
Pipes_diameter_type3	cm
U-value_pipes	(W/(m <sup>2</sup> .K))

**Fish**

Standing_stock	tons
FCR	kg/kg
Growth_rate	%/dag
Fish_energy_retention	MJ/kg

**Feed composition**

protein_content	kg/kg
fat_content	kg/kg
carbohydrates_content	kg/kg
protein_energy_content	MJ/kg
fat_energy_content	MJ/kg

carbohydrates_energy_content	MJ/kg
protein_digestibility	kg/kg
fat_digestibility	kg/kg
carbohydrates_digestibility	kg/kg

**Refreshment water**

Refresh_amount	m <sup>3</sup> /d
Refresh_temperature	°C
Refresh_when	h

**Design boundaries**

T_outside_air_min	°C
RH_outside_air_at_min_T	%
T_outside_air_max	°C
RH_outside_air_at_max_T	%
Trickling_ventilation_rate_min	m <sup>3</sup> /h
Trickling_ventilation_rate_max	m <sup>3</sup> /h
House_ventilation_rate_min	m <sup>3</sup> /h
House_ventilation_rate_max	m <sup>3</sup> /h

**Outside building temperatures**

delta_T_roof_outside	°C
delta_T_wall_outside	°C
delta_T_roof_wall_floor_inside	°C

**Default values**

v_i	m/s
T_ground	°C
sight_tanks_walls_roof	%

**Design requirements**

T_water_tank_min	°C
T_water_tank_max	°C
T_air_inside_min	°C
T_air_inside_max	°C
RH_air_inside_max	%
T_air_to_TF_min	°C

**Annex 3.2: Intermediate calculations**

Mollier	
T_inside	K
T_water	K
psat_air_inside	kPa
psat_air_water	kPa
p_air_inside	kPa
p_air_water	kPa

w_mollier_air_inside	*
w_mollier_air_water	*
dpt_air_inside (oC)	°C
dpt_air_water	°C
deltaH_vap_air_inside	kJ/kg
deltaH_vap_air_water	kJ/kg
deltaH_air_inside	kJ/kg
deltaH_air_water	kJ/kg
spvol_air_inside	*
spvol_air_water	*
dens_air_inside	*
dens_air_water	*
Water_evap_tanks	kg/h
Water_evap_solids	kg/h
Q_evap_tanks	MJ/h
Q_evap_solids	MJ/h
T_outside	K
T_water	K
T_house	K
psat_air_outside	kPa
psat_air_trickling_water	kPa
p_air_outside	kPa
p_air_trickling_water	kPa
w_mollier_air_outside	*
w_mollier_air_trickling_water	*
dpt_air_trickling_in	°C
dpt_air_trickling_out	°C
deltaH_vap_air_trickling_in	kJ/kg
deltaH_vap_air_trickling_out	kJ/kg
deltaH_air_trickling_in	kJ/kg
deltaH_air_trickling_out	kJ/kg
spvol_air_trickling_in	m <sup>3</sup> /kg
spvol_air_trickling_out	m <sup>3</sup> /kg
dens_air_trickling_in	kg/m <sup>3</sup>
dens_air_trickling_out	kg/m <sup>3</sup>
c_air_trickling_in	kg/m <sup>3</sup>
c_air_trickling_out	kg/m <sup>3</sup>
Evap_trickling_m3	kg/m <sup>3</sup>
Water_evap_trickling	kg/h
Q_evap_trickling	MJ/h
Q_total_trickling	MJ/h
Q_sensible	MJ/h
Convection_trickling	MJ/h
Radiation_trickling	MJ/h
Growth_rate_fish	kg/h
Feed_intake	kg/h
Gross_energy_feed	MJ/kg
psat_air_outside	kPa



psat_air_house	kPa
p_air_outside	kPa
p_air_house	kPa
w_mollier_air_outside	*
w_mollier_house	*
dpt_air_trickling_in	°C
dpt_air_trickling_out	°C
deltaH_vap_air_house_in	kJ/kg
deltaH_vap_air_house_out	kJ/kg
deltaH_air_house_in	kJ/kg
deltaH_air_house_out	kJ/kg
spvol_air_house_in	m <sup>3</sup> /kg
spvol_air_house_out	m <sup>3</sup> /kg
dens_air_house_in	m <sup>3</sup> /kg
dens_air_house_out	m <sup>3</sup> /kg
c_air_house_in	m <sup>3</sup> /kg
Total_evaporation	kg/h
Evaporation	kg/m <sup>3</sup>
c_air_house_out	kg/m <sup>3</sup>
Q_evap_house	MJ/h
Q_total_house	MJ/h
Q_sensible	MJ/h
p_inside	*
RH_inside	*

### Annex 3.3: Intermediate output

Heat_loss_walls_tanks_sens_air	MJ/h
convection	MJ/h
radiation	MJ/h
Heat_loss_tanks_surface	MJ/h
convection	MJ/h
radiation	MJ/h
evaporation	MJ/h
Heat_loss_trickling_filter	MJ/h
sensible	MJ/h
latent	MJ/h
convection and radiation	MJ/h
Heat_loss_pipes	MJ/h
Energy_intake_fish	MJ/h
Energy_feces	MJ/h
Energy_retention_fish	MJ/h
Heat_production_fish	MJ/h
Heat_pumps_into_water	MJ/h
Heat_pumps_into_air	MJ/h
Heat_loss_walls_building	MJ/h
convection	MJ/h

radiation	MJ/h
Heat_loss_roof_building	MJ/h
convection	MJ/h
radiation	MJ/h
Heat_loss_floor_building	MJ/h
conduction_under_tanks	MJ/h
conduction_rest	MJ/h
Heat_loss_ventilation_house	MJ/h