

# Keeping FatSmall solved

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## SUMMARY

This model was developed and applied by members of the EFSA Working Group on the transport/storage of fresh fishery products during the preparatory work on the BIOHAZ Scientific Opinion on the use of "tubs" for transporting and storing fresh fishery products (EFSA-Q-2019-00053) (<https://doi.org/10.2903/j.efsa.2020.6091>).

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# 1 Global Definitions

Date	Apr 9, 2020 9:02:33 PM
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## GLOBAL SETTINGS

Name	Keeping FatSmall solved.mph
Version	COMSOL Multiphysics 5.4 (Build: 388)

## USED PRODUCTS

COMSOL Multiphysics
Heat Transfer Module

## 1.1 PARAMETERS

### GENERAL

Name	Expression	Value	Description
Tfish_0	0 [degC]	273.15 K	Initial temperature fish
W_ice	38 [kg]	38 kg	Tubs-Ice weight
BW_ice	15 [kg]	15 kg	Box-Ice weight
TFoam_0	1.5 [degC]	274.65 K	Initial temperature foam
Twater_0	2.7 [degC]	275.85 K	Initial Water temperature (due to approximation)
fish_w	(29/2) [cm]	0.145 m	Width fish radius
fish_d	(15.5/2) [cm]	0.0775 m	Depth fish radius
fish_h	(0.85/2) [cm]	0.00425 m	Height fish radius
rho_fish	1025 [kg/m^3]	1025 kg/m <sup>3</sup>	Fish density
dT	1 [K]	1 K	Transition Interval
T_trans	0 [degC]	273.15 K	Transition temperature
lm	333.5 [kJ/kg]	3.335E5 J/kg	Latent heat of fusion
hh	5 [W/(m^2*K)]	5 W/(m <sup>2</sup> *K)	Heat transfer coefficient
BTfishsmall_0	Tfish_0	273.15 K	Box- Initial Temp manipulated fish
TTfishsmall_0	Tfish_0	273.15 K	Tub-Initial Temp manipulated fish
Tice_0	-0.5 [degC]	272.65 K	Initial ice

Name	Expression	Value	Description
			temperature (due to approximation)
Tair_0	2.7 [degC]	275.85 K	Initial temperature air inside box/tub
Bcontent_w	37 [cm]	0.37 m	Box-Content width
Bcontent_d	62 [cm]	0.62 m	Box-Content depth
Bthickness	5 [mm]	0.005 m	Box-material thickness
Bcontent_h	BBlock_h + Bice_h	0.22816 m	Box-Content height should be < 0.23
BW_fish	30 [kg]	30 kg	Box-Fish weight
TubThickness	3.6 [cm]	0.036 m	Tub-Thickness
content_w	93 [cm]	0.93 m	Tub-Content width
content_d	113 [cm]	1.13 m	Tub-Content depth
content_h	61 [cm]	0.61 m	Tub-Content height
W_fish	440 [kg]	440 kg	Tub-Tubs-Fish Weight
V_water	100 [L]	0.1 m <sup>3</sup>	Tub-Water liters
theta	$(VT_{fish\_wish} - V_{smallfish}) / (VT_{fish\_wish} - V_{smallfish} + V_{water\_wish})$	0.81092	Volume fraction
box_w	$Bcontent\_w + 2*Bthickness$	0.38 m	Box-width (should be < 0.45)
box_d	$Bcontent\_d + 2*Bthickness$	0.63 m	Box-depth (should be < 0.8)
box_h	$BBlock\_h + Bthickness + Bice\_h$	0.23316 m	Box-height (should be < 0.27)
Bdw	Bthickness	0.005 m	Box-Foam thickness width
Bdd	Bthickness	0.005 m	Box-Foam thickness depth
Bdh	Bthickness	0.005 m	Box-Foam thickness height on bottom
BBlock_w	Bcontent_w	0.37 m	Box-Width of block with air and fish

Name	Expression	Value	Description
BBlock_d	Bcontent_d	0.62 m	Box-Depth of block with air and fish
BBlock_h	$(BV_{\text{smallfish}} + (BVT_{\text{fish\_wish}} - BV_{\text{smallfish}})/\theta_B)/(BBlock_w * BBlock_d)$	0.15693 m	Box-Height of block with fish and air
BVblock	$(BBlock_w * BBlock_d * BBlock_h)$	0.036 m <sup>3</sup>	Box-Total volume of the block with air and fish
Bice_h	$BV_{\text{ice\_Wish}}/(Bcontent_w * Bcontent_d)$	0.071229 m	Box-Ice thickness
BVTfish	$BV_{\text{block}} * \theta_B + BV_{\text{smallfish}}$	0.029593 m <sup>3</sup>	Box-Volume block with air and fish
BVTfish_wish	$(BW_{\text{fish}}/\rho_{\text{fish}})$	0.029268 m <sup>3</sup>	Box-Wish Volume fish total
BVice	$Bice_h * Bcontent_d * Bcontent_w$	0.01634 m <sup>3</sup>	Box-Model ice volume
BVice_Wish	$(BW_{\text{ice}}/918[\text{kg/m}^3])$	0.01634 m <sup>3</sup>	Box-Wish Volume ice
TporousBOX_0	$T_{\text{fish}_0} * \theta_B + T_{\text{air}_0} * (1 - \theta_B)$	273.66 K	Box-Initial temperature for block of air and fish
theta_B	theta	0.81092	Box-Effective volume air/fish
BVsmallfish	$2 * (4/3) * \pi * (\text{fish}_h * \text{fish}_d * \text{fish}_w)$	4.0011E-4 m <sup>3</sup>	Box-Small fish volume
tub_w	$\text{content}_w + 2 * dw$	1.002 m	Tub-width
tub_d	$\text{content}_d + 2 * dd$	1.202 m	Tub-depth
tub_h	$\text{content}_h + 2 * dh$	0.682 m	Tub-height
dw	TubThickness	0.036 m	Tub-Foam thickness width
dd	TubThickness	0.036 m	Tub-Foam thickness depth
dh	TubThickness	0.036 m	Tub-Foam thickness height
Block_w	content_w	0.93 m	Tub-Block fish/water width
Block_d	content_d	1.13 m	Tub-Block fish/water depth
Block_h	$(VT_{\text{fish\_wish}} + V_{\text{water\_wish}})/((\text{content}_w) * (\text{content}_d))$	0.50363 m	Tub-Block fish/water height

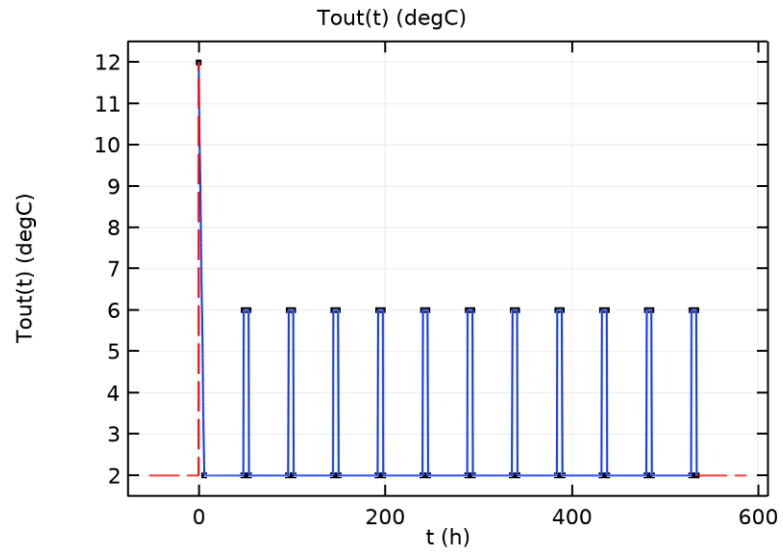


Name	Expression	Value	Description
Vair	$(\text{content\_w} * \text{content\_d} * (\text{content\_h} - \text{ice\_h} - \text{Block\_h}))$	0.070386 m <sup>3</sup>	Tub-Air volume
air_h	$(\text{Vair}) / (\text{content\_d} * \text{content\_w})$	0.066977 m	Tub-Air layer height
VTfish	$\text{Vblock} * \text{theta} + \text{Vsmallfish}$	0.42959 m <sup>3</sup>	Tub-Model Volume total fish
VTfish_wish	$(\text{W\_fish} / \text{rho\_fish})$	0.42927 m <sup>3</sup>	Tub-Wish Volume fish total
Vice	$\text{ice\_h} * \text{content\_d} * \text{content\_w}$	0.041394 m <sup>3</sup>	Tub-Model Volume ice
Vice_Wish	$(\text{W\_ice} / 918 [\text{kg}/\text{m}^3])$	0.041394 m <sup>3</sup>	Tub-Wish Volume ice
Vwater	$\text{Vblock} * (1 - \text{theta})$	0.10008 m <sup>3</sup>	Tub-Model volume water
Vwater_wish	$\text{V\_water}$	0.1 m <sup>3</sup>	Tub-Wish Volume water
ice_h	$\text{Vice\_Wish} / (\text{content\_w} * \text{content\_d})$	0.039389 m	Tub-Ice thickness
TporousTUB_0	$\text{Tfish}_0 * \text{theta} + \text{Twater}_0 * (1 - \text{theta})$	273.66 K	Tub-Initial temperature for block of water/fish
Vsmallfish	$2 * (4/3) * \pi * (\text{fish\_h} * \text{fish\_d} * \text{fish\_w})$	4.0011E-4 m <sup>3</sup>	Tub-Small fish volume
Vblock	$\text{Block\_w} * \text{Block\_d} * \text{Block\_h}$	0.52927 m <sup>3</sup>	Tub-Block water/fish volume

## 1.2 FUNCTIONS

### 1.2.1 T outside fridge 1

Function names	Tout
Function type	Interpolation



$T$  outside fridge <sup>1</sup>

<sup>1</sup> Simulations are run for 5 days (5\*24 hours), but input variables are defined for larger times to avoid problems if final time is changed.

## 2 Tub

### 2.1 DEFINITIONS

#### 2.1.1 Fish

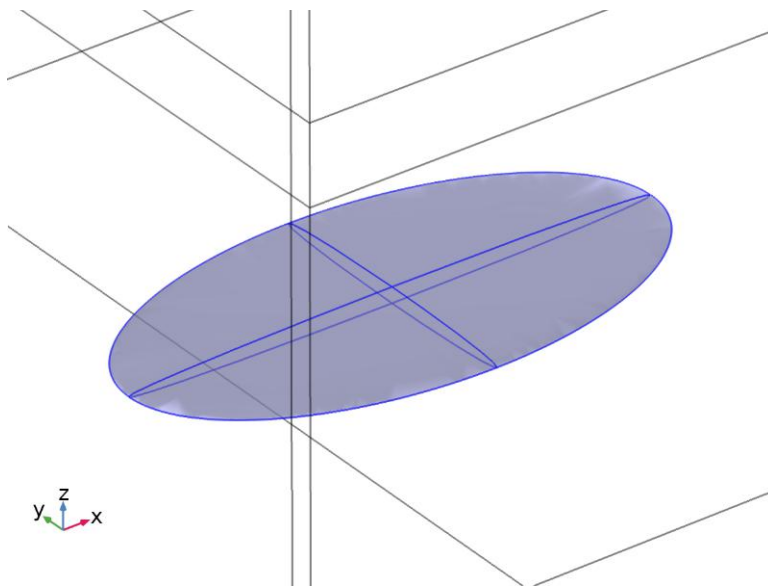
##### Probes

##### TUB-max surface middle fish

Probe type	Boundary probe
------------	----------------

##### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 27–34



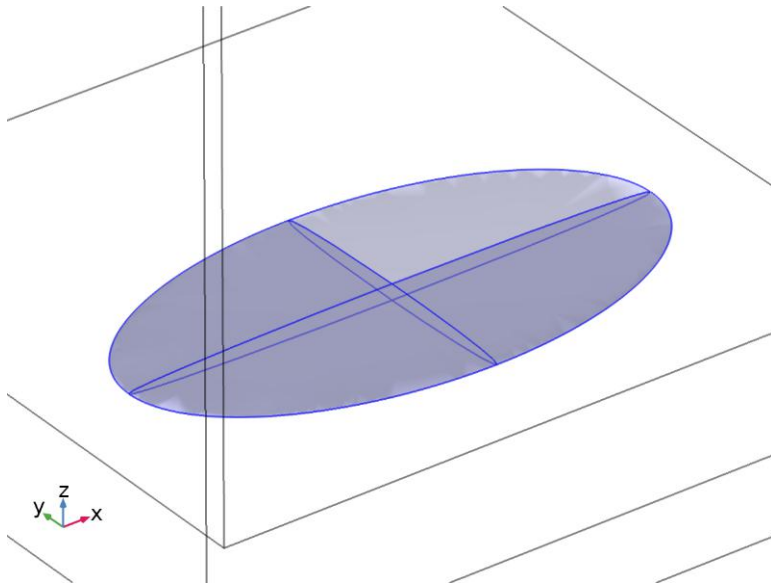
*Selection*

##### TUB-max surface corner fish

Probe type	Boundary probe
------------	----------------

##### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 19–25



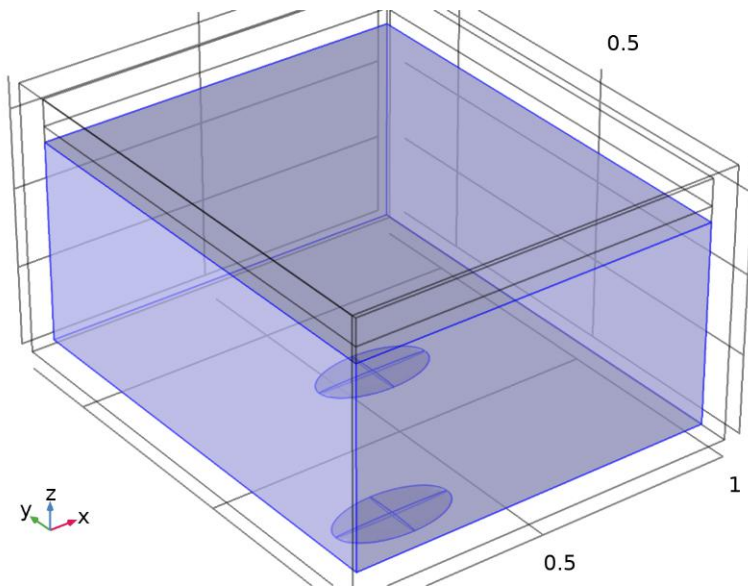
*Selection*

**TUB-Max**

Probe type	Domain probe
------------	--------------

**SELECTION**

Geometric entity level	Domain
Selection	Domains 2, 5-6



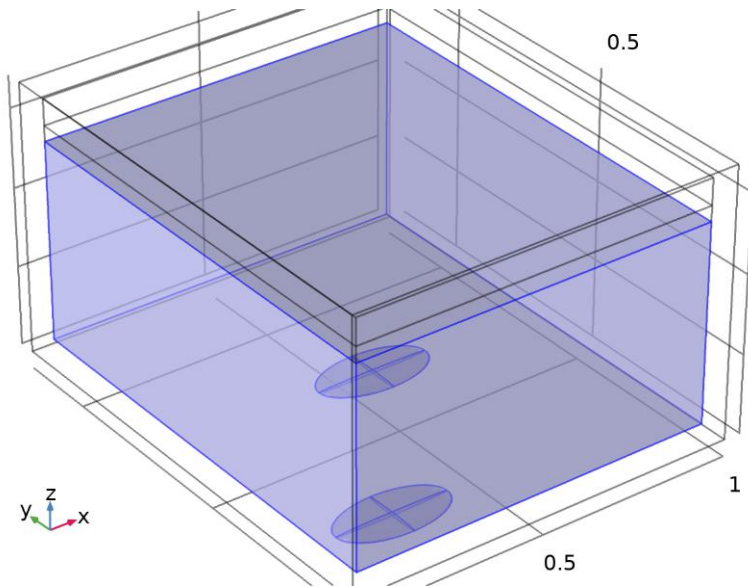
*Selection*

**TUB-Min**

Probe type	Domain probe
------------	--------------

### SELECTION

Geometric entity level	Domain
Selection	Domains 2, 5-6



*Selection*

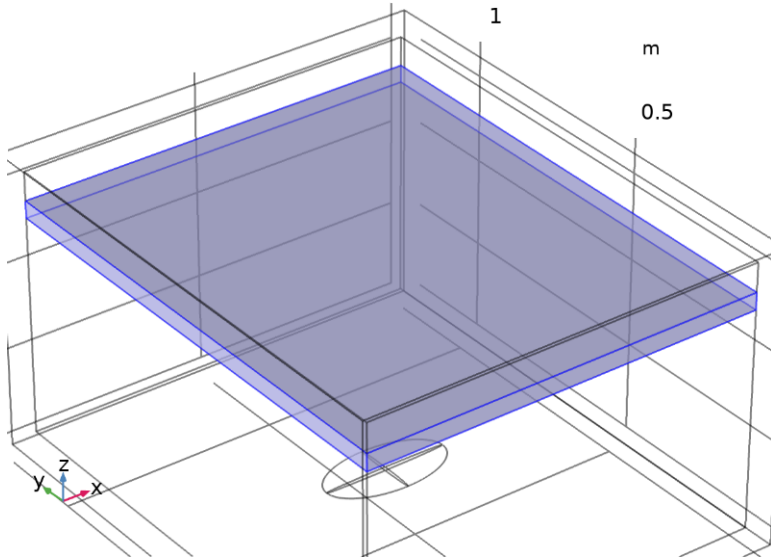
## 2.1.2 Check outside fish

%ice

Probe type	Domain probe
------------	--------------

### SELECTION

Geometric entity level	Domain
Selection	Domain 3



*Selection*

**Outside Temp**

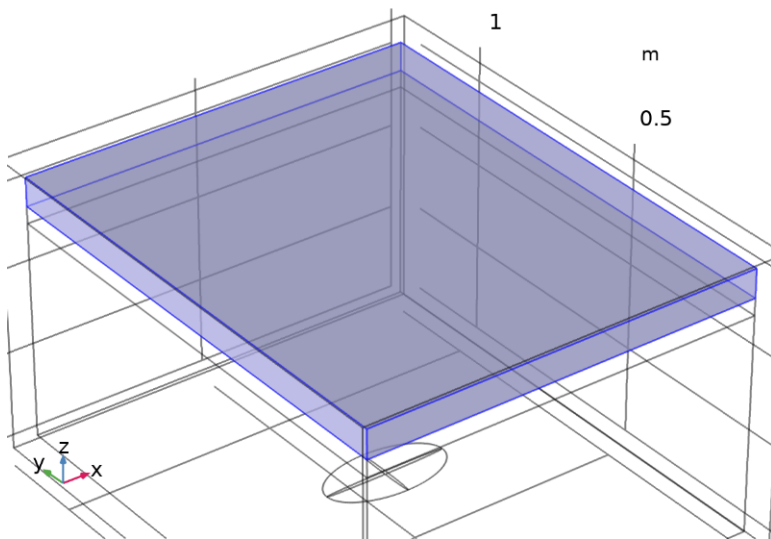
Probe type Global variable probe

**Air Average**

Probe type Domain probe

**SELECTION**

Geometric entity level	Domain
Selection	Domain 4



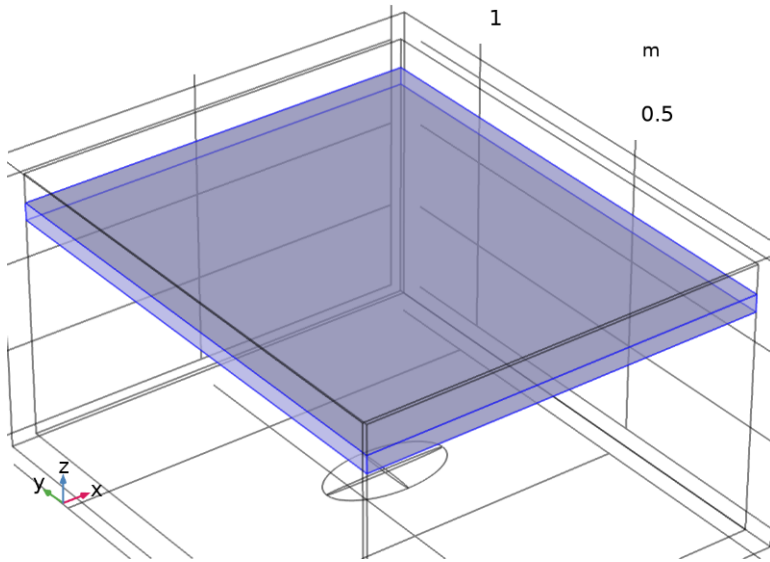
*Selection*

### Ice Average temp

Probe type	Domain probe
------------	--------------

#### SELECTION

Geometric entity level	Domain
Selection	Domain 3



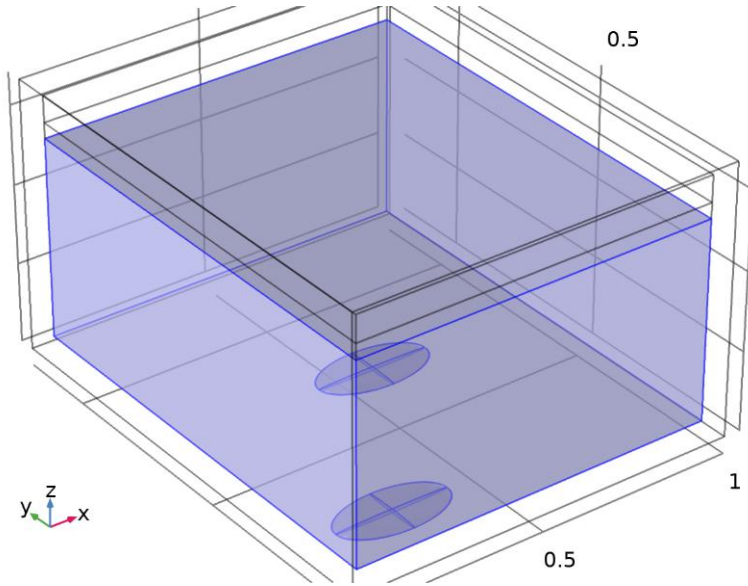
*Selection*

### Water Average

Probe type	Domain probe
------------	--------------

#### SELECTION

Geometric entity level	Domain
Selection	Domain 2



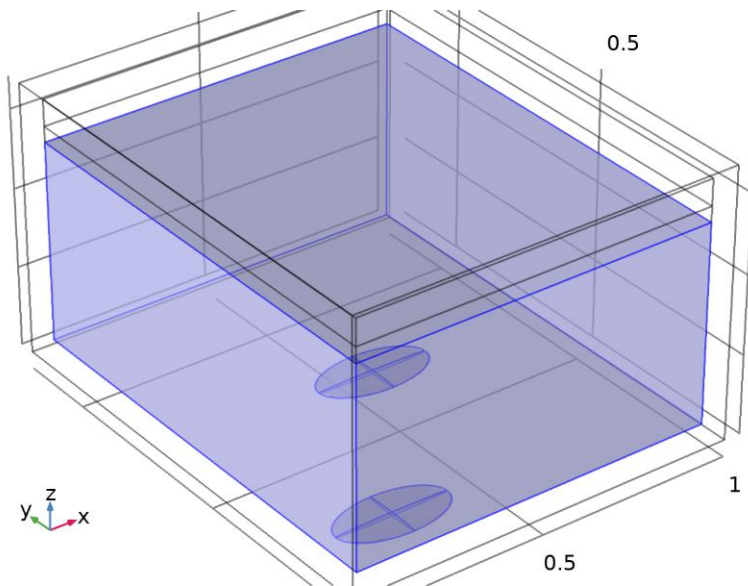
*Selection*

**Water Maximum**

Probe type Domain probe

SELECTION

Geometric entity level	Domain
Selection	Domain 2



*Selection*

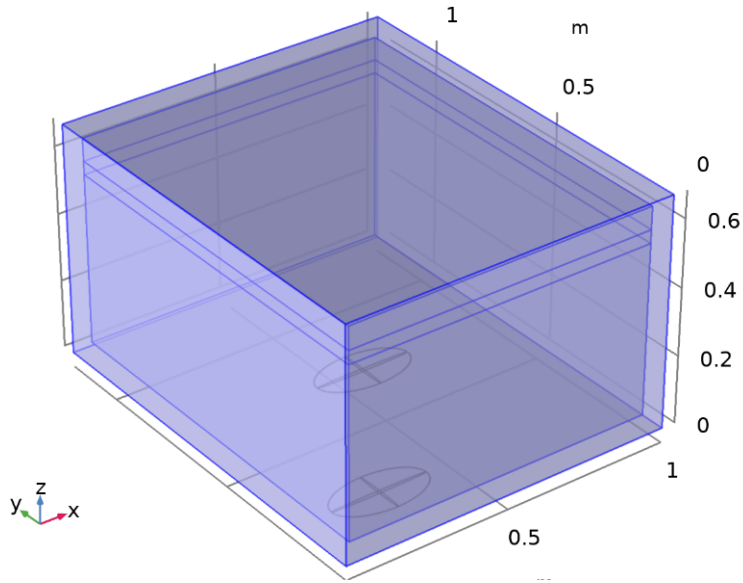
**Foam average**

Probe type Domain probe



SELECTION

Geometric entity level	Domain
Selection	Domain 1



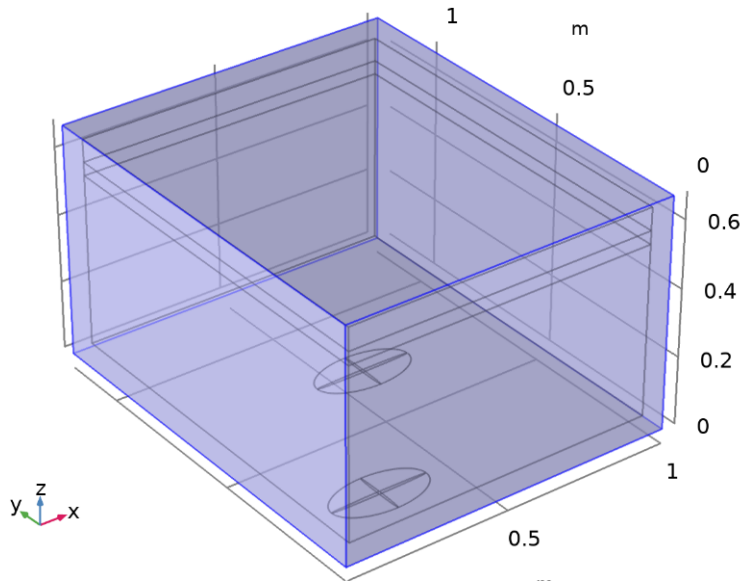
*Selection*

**Foam maximum boundary**

Probe type	Boundary probe
------------	----------------

SELECTION

Geometric entity level	Boundary
Selection	Boundaries 1-5, 38



Selection

### 2.1.3 Coordinate Systems

#### Boundary System 1

Coordinate system type	Boundary system
Tag	sys1

#### COORDINATE NAMES

First	Second	Third
t1	t2	n

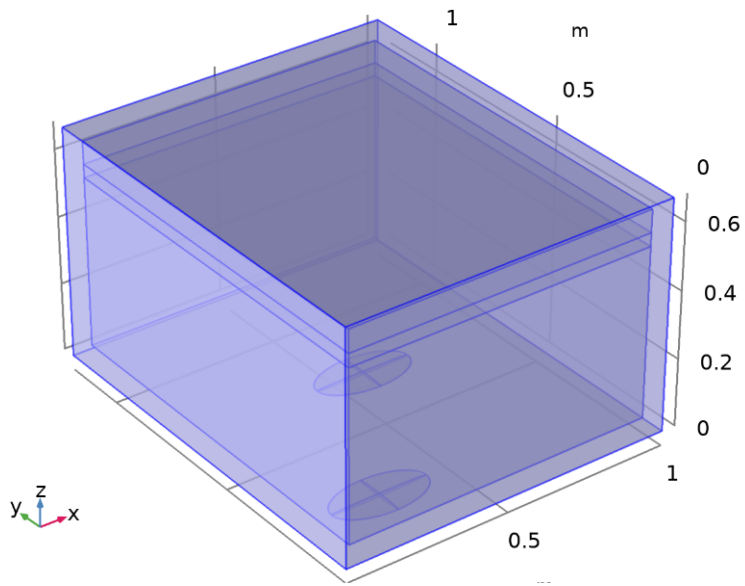
### 2.1.4 Moving Mesh

#### Rotating Domain 1

Tag	rot1
-----	------

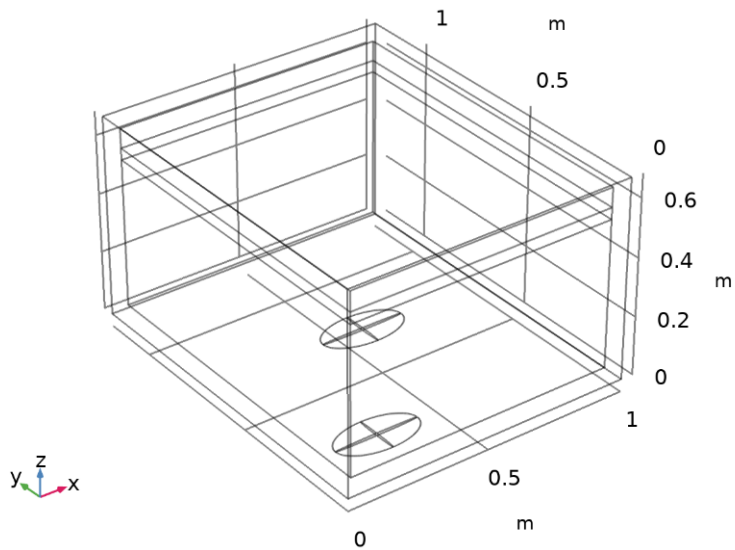
#### SELECTION

Geometric entity level	Domain
Selection	Domains 1–6



Selection

## 2.2 GEOMETRY 1



Geometry 1

### UNITS

Length unit	m
Angular unit	deg

### 2.2.1 Block TUB (blk1)

#### POSITION

Description	Value
-------------	-------

Description	Value
Position	{0, 0, 0}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
Width	tub_w
Depth	tub_d
Height	tub_h

### 2.2.2 Block Air (blk5)

#### POSITION

Description	Value
Position	{dw, dd, dh + Block_h + ice_h}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
Width	content_w
Depth	content_d
Height	air_h

### 2.2.3 Block Ice (blk3)

#### POSITION

Description	Value
Position	{dw, dd, dh + Block_h}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
-------------	-------

Description	Value
Width	content_w
Depth	content_d
Height	ice_h

#### 2.2.4 Block Fish (blk6)

##### POSITION

Description	Value
Position	{dw, dd, dh}

##### AXIS

Description	Value
Axis type	z - axis

##### SIZE AND SHAPE

Description	Value
Width	Block_w
Depth	Block_d
Height	Block_h

#### 2.2.5 Fish bottom (elp1)

##### POSITION

Description	Value
Position	{dw + fish_w + 0.02, dd + fish_d + 0.02, dh + fish_h + 0.02}

##### AXIS

Description	Value
Axis type	z - axis

##### SIZE

Description	Value
a-semiaxis	fish_w
b-semiaxis	fish_d
c-semiaxis	fish_h

#### 2.2.6 Fish middle (elp2)

##### POSITION

Description	Value
-------------	-------

Description	Value
Position	{dw + Block_w/2, dd + Block_d/2, dh + fish_h + 0.02}

#### AXIS

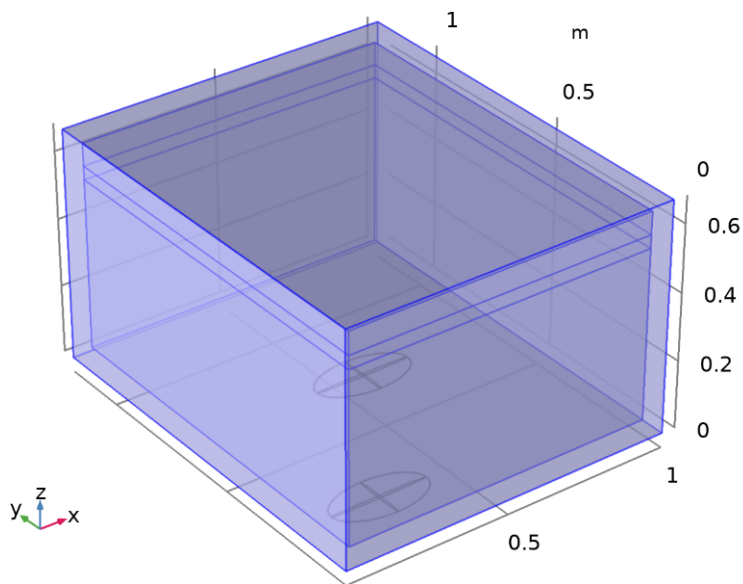
Description	Value
Axis type	z - axis

#### SIZE

Description	Value
a-semiaxis	fish_w
b-semiaxis	fish_d
c-semiaxis	fish_h

## 2.3 MATERIALS

### 2.3.1 PE (Polyethylene foam)



*PE (Polyethylene foam)*

#### SELECTION

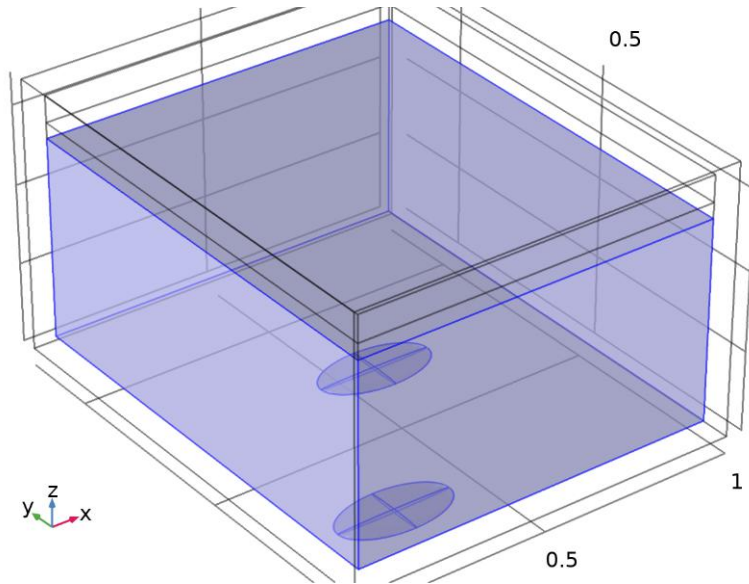
Geometric entity level	Domain
Selection	Domain 1

#### MATERIAL PARAMETERS

Name	Value	Unit
Thermal conductivity	0.05	W/(m·K)
Density	70	kg/m <sup>3</sup>

Name	Value	Unit
Heat capacity at constant pressure	2.3*1000	J/(kg·K)

### 2.3.2 Water, liquid



*Water, liquid*

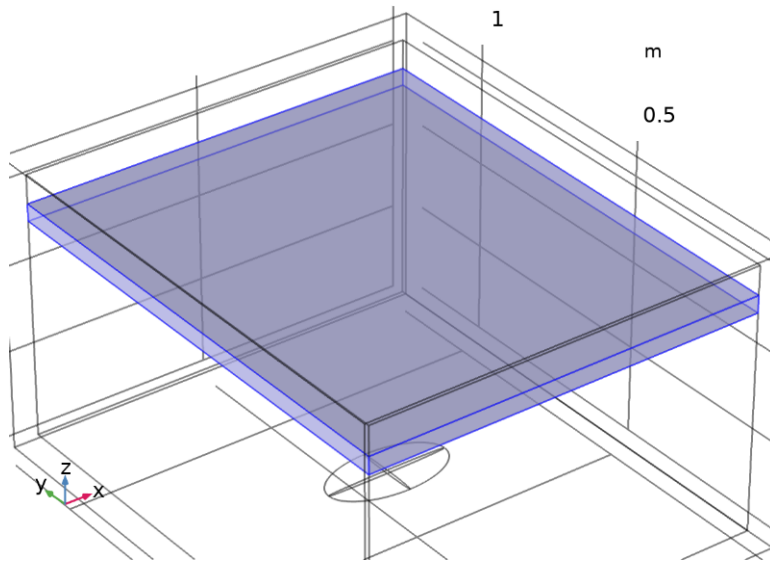
#### SELECTION

Geometric entity level	Domain
Selection	Domain 2

#### MATERIAL PARAMETERS

Name	Value	Unit
Ratio of specific heats	gamma_w(T)	1
Heat capacity at constant pressure	Cp(T)	J/(kg·K)
Density	rho(T)	kg/m <sup>3</sup>
Thermal conductivity	k(T)	W/(m·K)

### 2.3.3 Ice



*Ice*

#### SELECTION

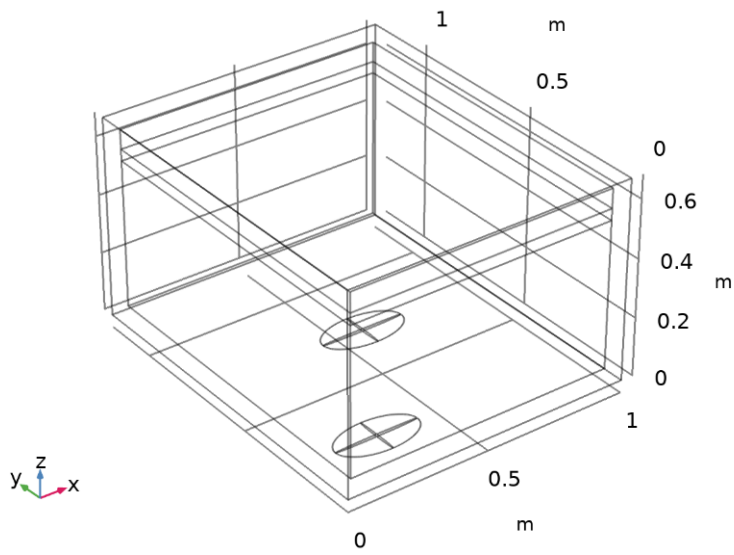
Geometric entity level	Domain
Selection	Domain 3

#### MATERIAL PARAMETERS

Name	Value	Unit
Thermal conductivity	2.31	W/(m·K)
Density	918	kg/m <sup>3</sup>
Heat capacity at constant pressure	2052	J/(kg·K)



### 2.3.4 Haddock

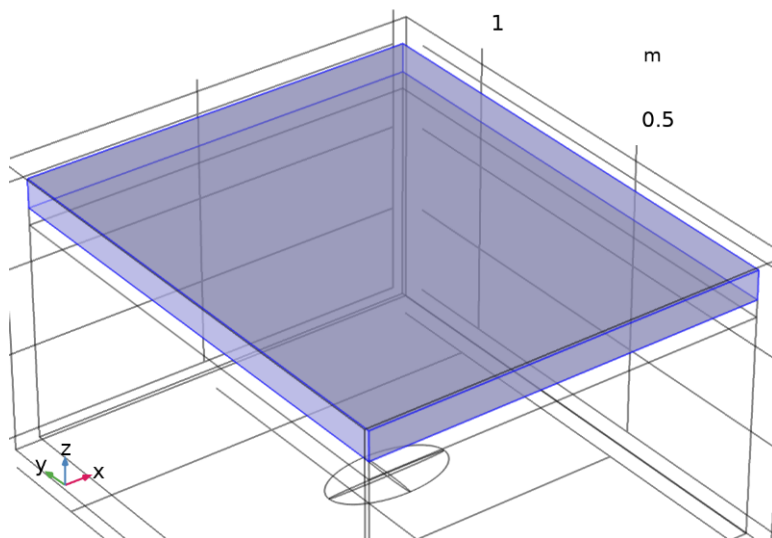


*Haddock*

#### SELECTION

Geometric entity level	Domain
Selection	No domains

### 2.3.5 Air



*Air*

#### SELECTION

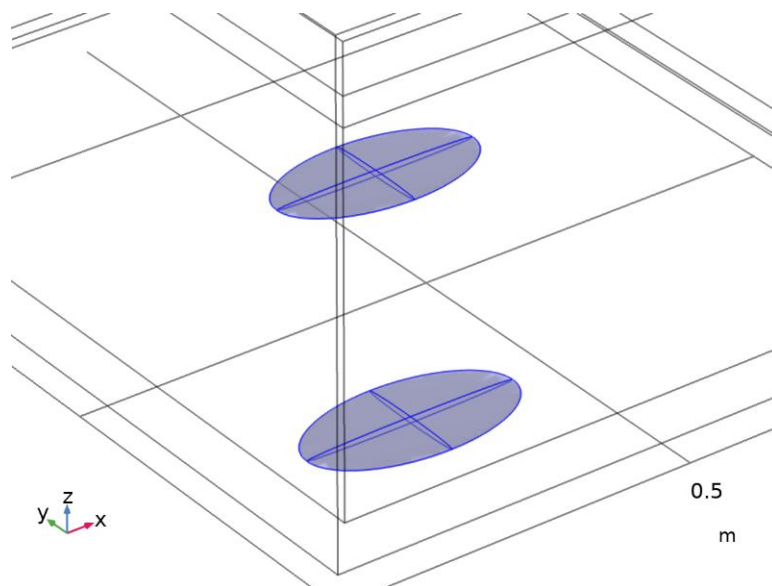
Geometric entity level	Domain
------------------------	--------

Selection	Domain 4
-----------	----------

#### MATERIAL PARAMETERS

Name	Value	Unit
Ratio of specific heats	1.4	1
Heat capacity at constant pressure	$C_p(T)$	J/(kg·K)
Density	$\rho(p,A,T)$	kg/m <sup>3</sup>
Thermal conductivity	$k(T)$	W/(m·K)

### 2.3.6 FAT



*FAT*

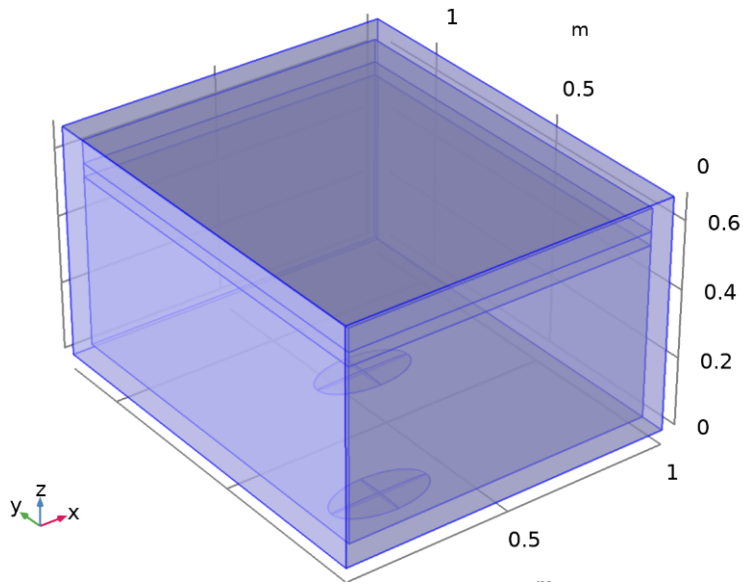
#### SELECTION

Geometric entity level	Domain
Selection	Domains 5–6

#### MATERIAL PARAMETERS

Name	Value	Unit
Density	1025	kg/m <sup>3</sup>
Heat capacity at constant pressure	3.5	J/(kg·K)
Thermal conductivity	0.41	W/(m·K)

## 2.4 HEAT TRANSFER IN POROUS MEDIA



*Heat Transfer in Porous Media*

### SELECTION

Geometric entity level	Domain
Selection	Domains 1–6

### EQUATIONS

$$(\rho c_p)_{\text{eff}} \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{vd}}$$

$$\mathbf{q} = -k_{\text{eff}} \nabla T$$

### 2.4.1 Interface settings

#### Discretization

##### SETTINGS

Description	Value
Temperature	Linear

#### Physical model

##### SETTINGS

Description	Value
Heat transfer in biological tissue	Off
Isothermal domain	Off
Heat transfer in porous media	On
Porous matrix model	Standard

Description	Value
Heat transfer in alloys	Off
Reference temperature	User defined
Reference temperature	3 [degC]

## FEATURES

Porous Medium 1
Initial Values 1
Thermal Insulation 1
Solid Foam
Initial Foam
Fluid Air
Initial Air
ICE
Initial Values ICE
Solid fish
Initial Fish
Initial Fish bottom
Initial Fish middle
Heat Flux 1

### 2.4.2 Porous Medium 1

#### EQUATIONS

$$(\rho c_p)_{\text{eff}} \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_p + Q_{vd}$$

$$\mathbf{q} = -k_{\text{eff}} \nabla T$$

$$(\rho c_p)_{\text{eff}} = \theta_p \rho_p c_{p,p} + (1 - \theta_p) \rho c_p$$

$$k_{\text{eff}} = \theta_p k_p + (1 - \theta_p) k + k_{\text{disp}}$$

### 2.4.3 Thermal Insulation 1

#### EQUATIONS

$$-\mathbf{n} \cdot \mathbf{q} = 0$$

### 2.4.4 Solid Foam

#### EQUATIONS

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$

$$\mathbf{q} = -k \nabla T$$

### 2.4.5 Fluid Air

EQUATIONS

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_p + Q_{\text{vd}}$$

$$\mathbf{q} = -k \nabla T$$

### 2.4.6 ICE

EQUATIONS

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$

$$\mathbf{q} = -k \nabla T$$

### Phase Change Material 1

EQUATIONS

$$\rho = \rho_{\text{solid}}$$

$$c_p = \theta_1 c_{p1} + \theta_2 c_{p2} + L_{1 \rightarrow 2} \frac{\partial \alpha_m}{\partial T}$$

$$\alpha_m = \frac{1}{2} \frac{\theta_2 - \theta_1}{\theta_1 + \theta_2}$$

$$k = \theta_1 k_1 + \theta_2 k_2$$

$$\theta_1 + \theta_2 = 1$$

### 2.4.7 Solid fish

EQUATIONS

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$

$$\mathbf{q} = -k \nabla T$$

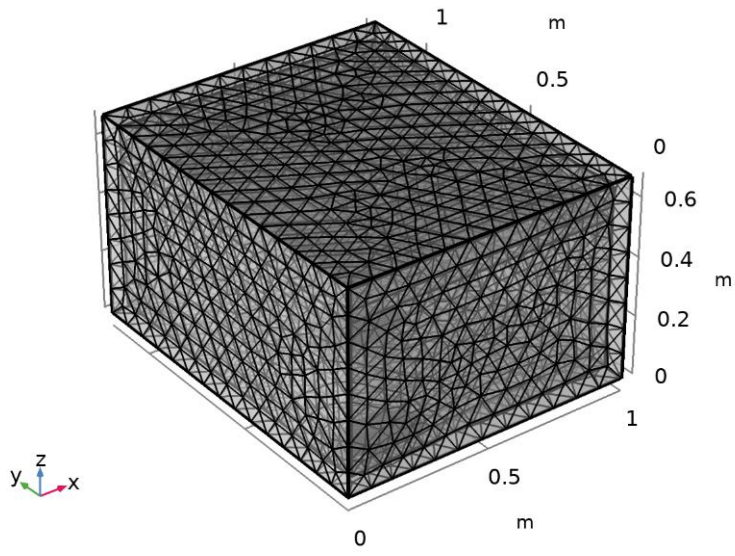
### 2.4.8 Heat Flux 1

EQUATIONS

$$-\mathbf{n} \cdot \mathbf{q} = q_0$$

$$q_0 = h(T_{\text{ext}} - T)$$

## 2.5 MESH 8



*Mesh 8*

### 3 Box

#### 3.1 DEFINITIONS

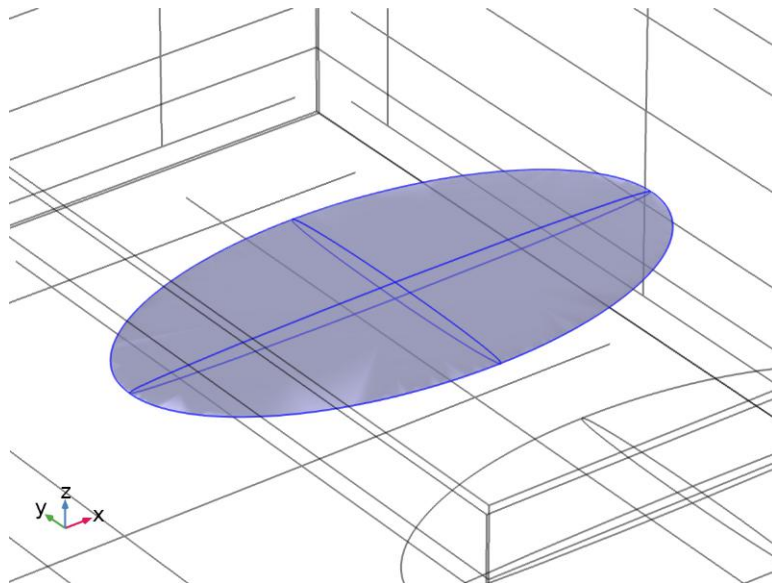
##### 3.1.1 Probes

###### BOX- max surface middle fish

Probe type	Boundary probe
------------	----------------

###### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 23–26, 31–34



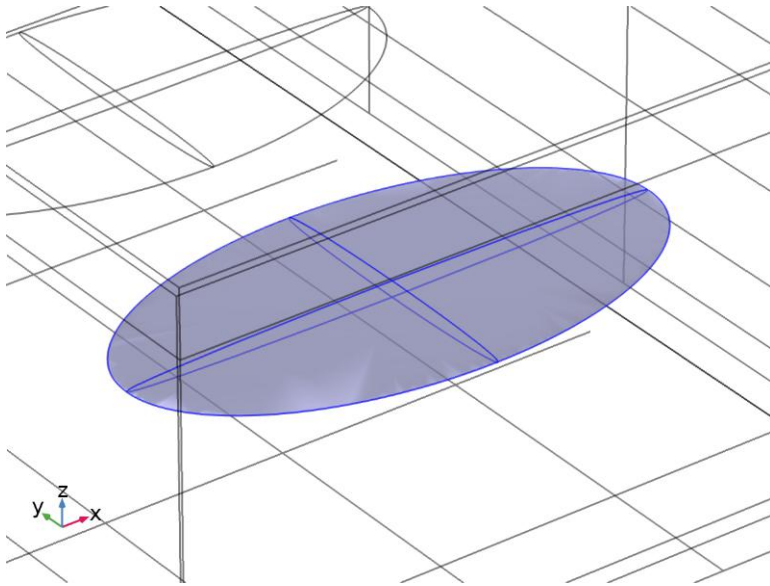
*Selection*

###### BOX- max surface corner

Probe type	Boundary probe
------------	----------------

###### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 19–22, 27–30



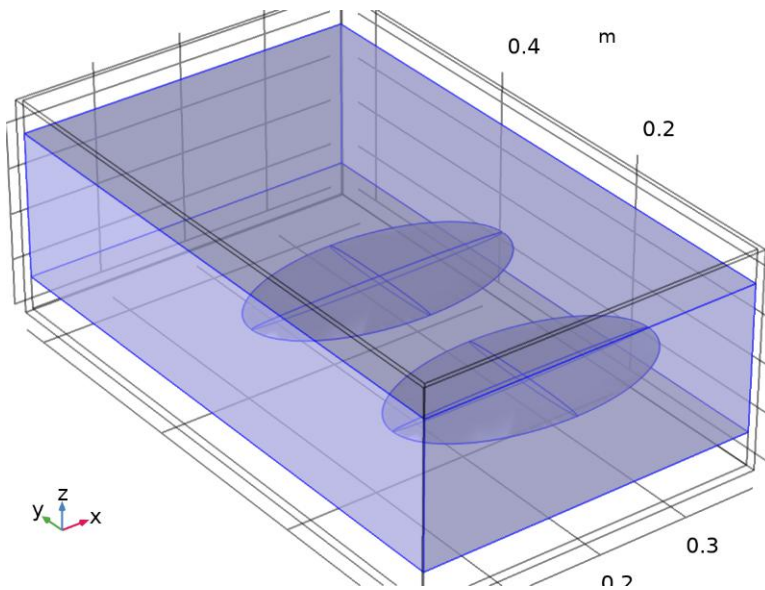
*Selection*

**BOX-max**

Probe type	Domain probe
------------	--------------

**SELECTION**

Geometric entity level	Domain
Selection	Domains 3, 5-6



*Selection*

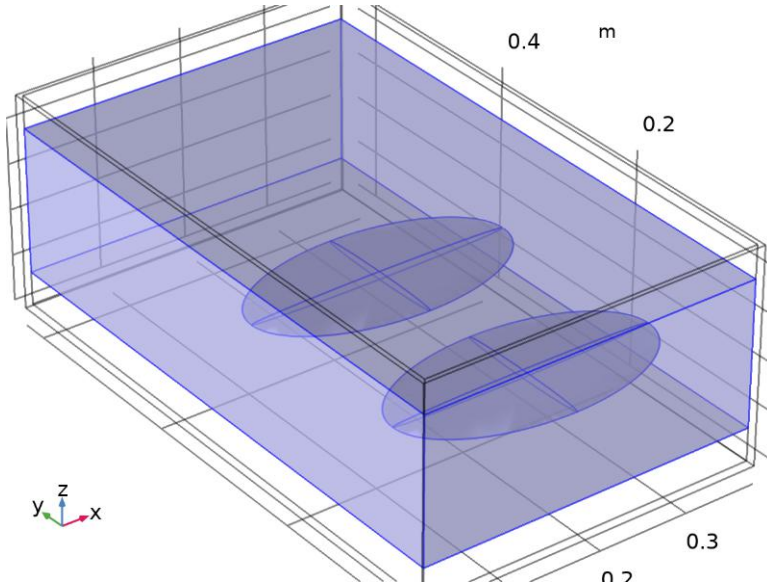
**BOX-min**

Probe type	Domain probe
------------	--------------



SELECTION

Geometric entity level	Domain
Selection	Domains 3, 5-6



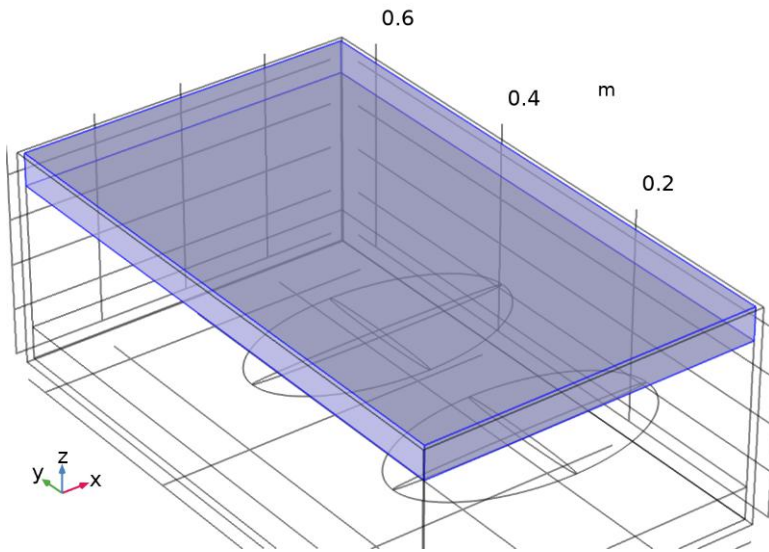
*Selection*

**% top ice average**

Probe type	Domain probe
------------	--------------

SELECTION

Geometric entity level	Domain
Selection	Domain 4



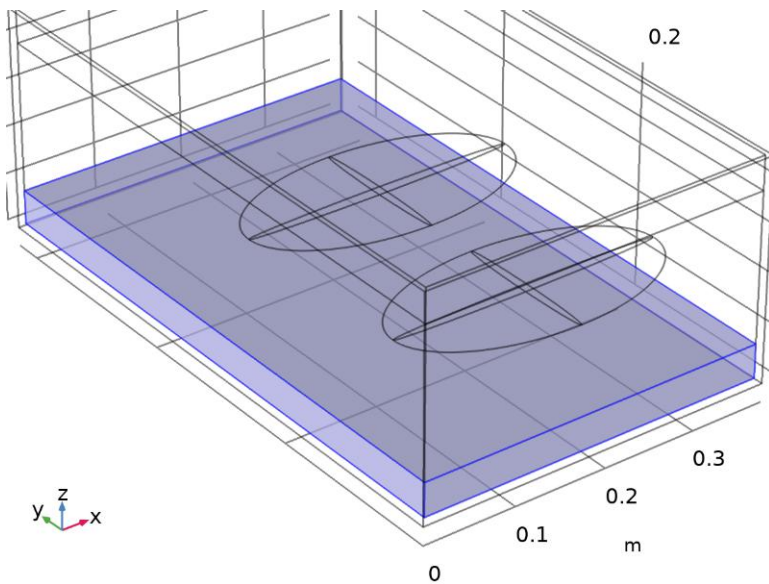
*Selection*

**% bottom ice average 1**

Probe type Domain probe

SELECTION

Geometric entity level	Domain
Selection	Domain 2



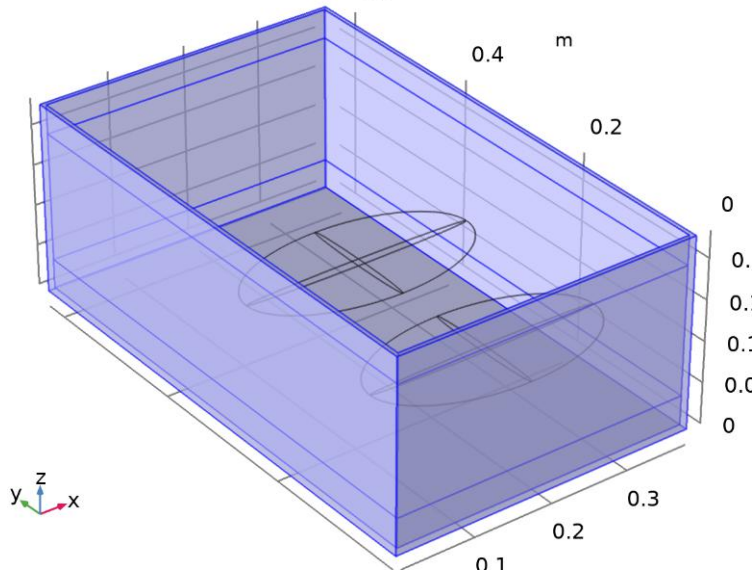
*Selection*

**BFoam Average**

Probe type Domain probe

### SELECTION

Geometric entity level	Domain
Selection	Domain 1



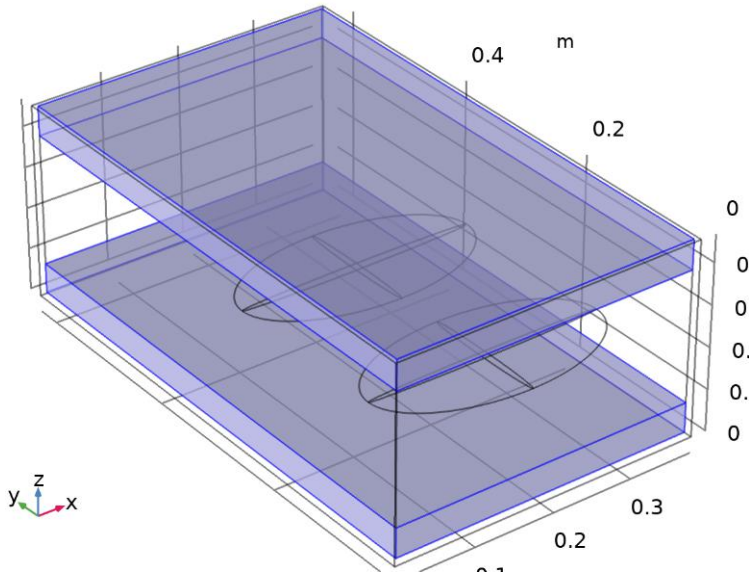
*Selection*

### Bice Average

Probe type	Domain probe
------------	--------------

### SELECTION

Geometric entity level	Domain
Selection	Domains 2, 4



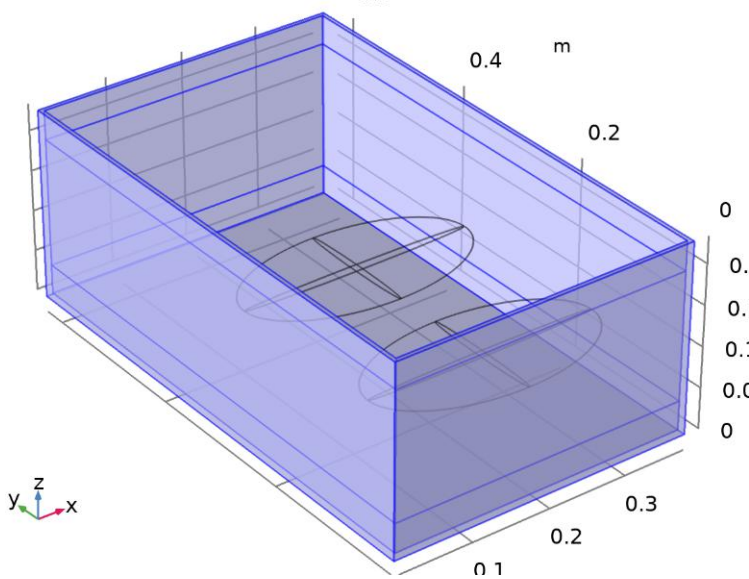
*Selection*

**BFoam Maximum**

Probe type Domain probe

SELECTION

Geometric entity level	Domain
Selection	Domain 1



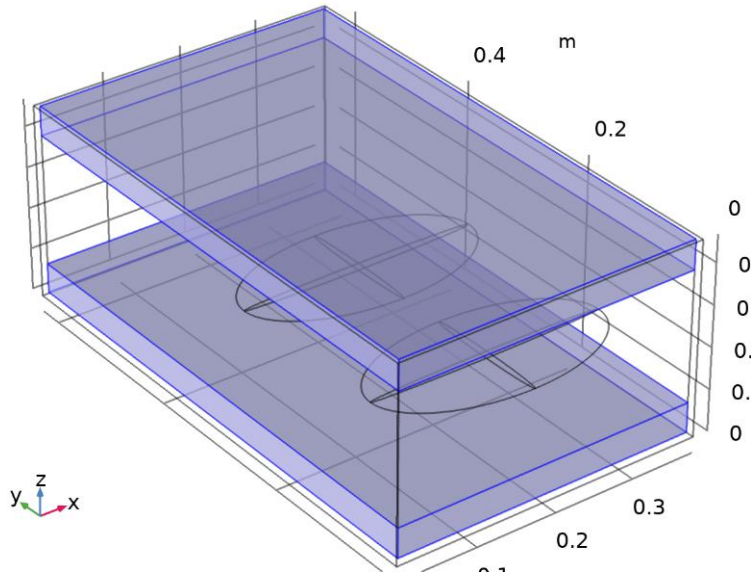
*Selection*

**Ice temp**

Probe type Domain probe

## SELECTION

Geometric entity level	Domain
Selection	Domains 2, 4



*Selection*

## 3.1.2 Coordinate Systems

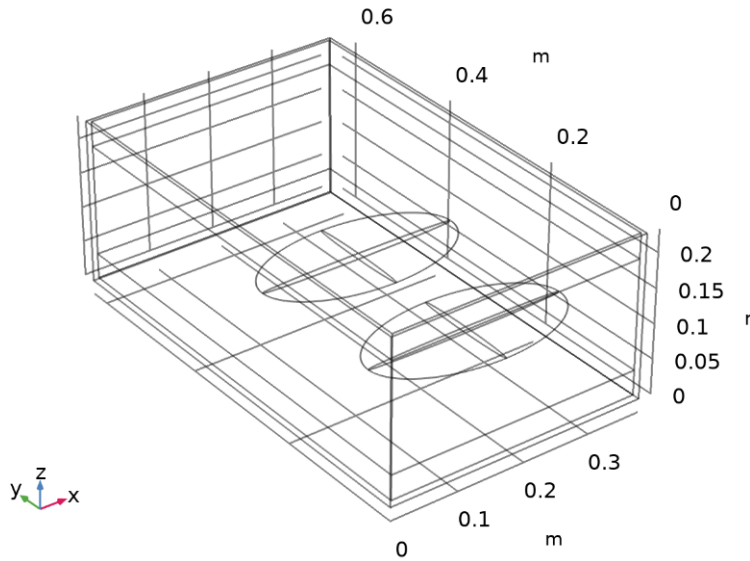
### Boundary System 2

Coordinate system type	Boundary system
Tag	sys2

## COORDINATE NAMES

First	Second	Third
t1	t2	n

## 3.2 GEOMETRY 2



Geometry 2

### UNITS

Length unit	m
Angular unit	deg

### 3.2.1 Box (blk1)

#### POSITION

Description	Value
Position	{0, 0, 0}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
Width	box_w
Depth	box_d
Height	box_h

### 3.2.2 IceTop (blk2)

#### POSITION

Description	Value
-------------	-------

Description	Value
Position	{Bdw, Bdd, Bdh + BBlock_h + Bice_h/2}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
Width	Bcontent_w
Depth	Bcontent_d
Height	Bice_h/2

### 3.2.3 IceBottom (blk3)

#### POSITION

Description	Value
Position	{Bdw, Bdd, Bdh}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
Width	Bcontent_w
Depth	Bcontent_d
Height	Bice_h/2

### 3.2.4 Fish/air (blk4)

#### POSITION

Description	Value
Position	{Bdw, Bdd, Bdh + Bice_h/2}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
-------------	-------

Description	Value
Width	Bcontent_w
Depth	Bcontent_d
Height	BBlock_h

### 3.2.5 Fish Corner (elp1)

#### POSITION

Description	Value
Position	{Bdw + BBlock_w/2, Bdd + fish_d + 0.02, Bdh + Bice_h/2 + BBlock_h/2}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE

Description	Value
a-semiaxis	fish_w
b-semiaxis	fish_d
c-semiaxis	fish_h

### 3.2.6 IceTop 1 (blk5)

#### POSITION

Description	Value
Position	{Bdw, Bdd, Bdh + BBlock_h + Bice_h/2}

#### AXIS

Description	Value
Axis type	z - axis

#### SIZE AND SHAPE

Description	Value
Width	Bcontent_w
Depth	Bcontent_d
Height	Bice_h/2

### 3.2.7 Fish middle (elp2)

#### POSITION

Description	Value
-------------	-------



Description	Value
Position	{Bdw + BBlock_w/2, Bdd + BBlock_d/2, Bdh + Bice_h/2 + BBlock_h/2}

#### AXIS

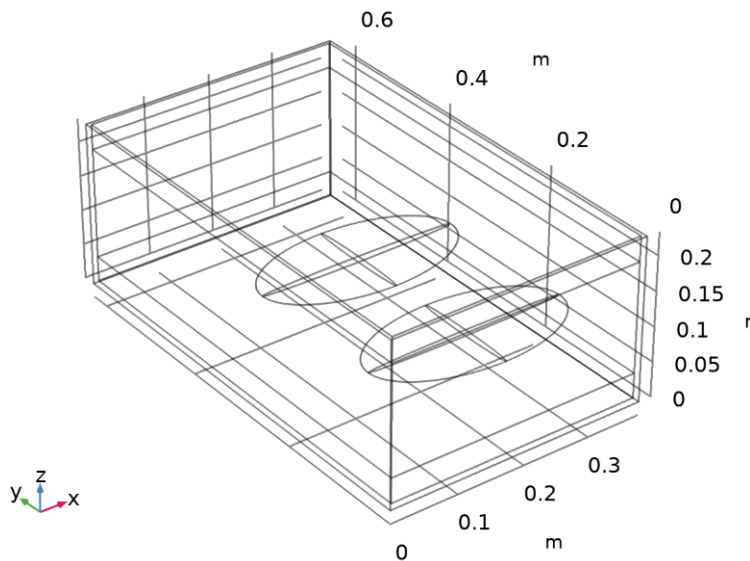
Description	Value
Axis type	z - axis

#### SIZE

Description	Value
a-semiaxis	fish_w
b-semiaxis	fish_d
c-semiaxis	fish_h

### 3.3 MATERIALS

#### 3.3.1 Haddock

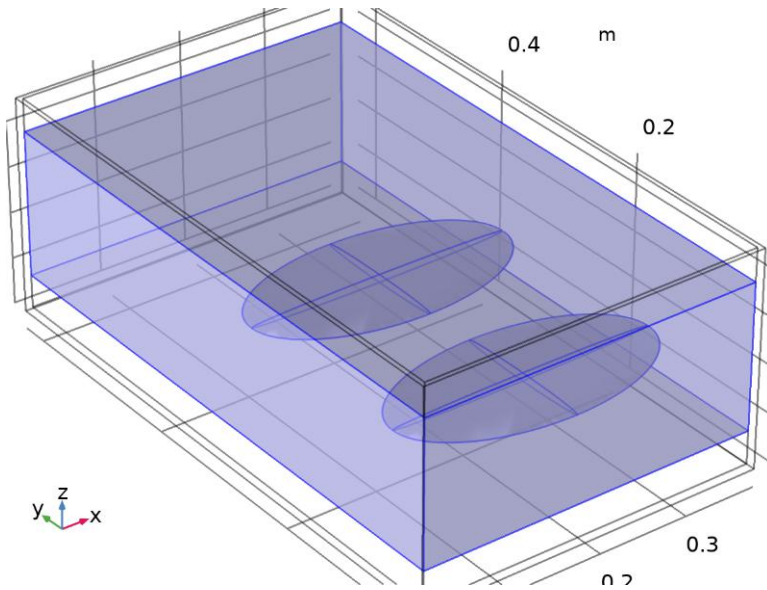


*Haddock*

#### SELECTION

Geometric entity level	Domain
Selection	No domains

### 3.3.2 Air



*Air*

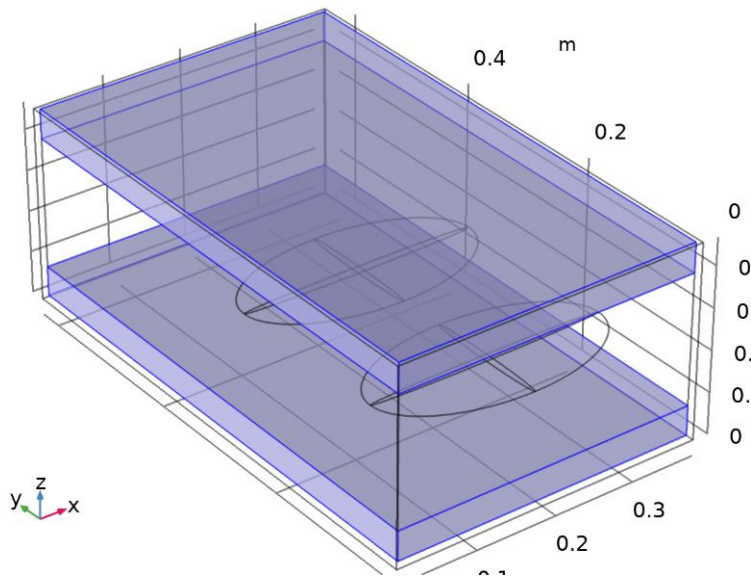
#### SELECTION

Geometric entity level	Domain
Selection	Domain 3

#### MATERIAL PARAMETERS

Name	Value	Unit
Ratio of specific heats	1.4	1
Heat capacity at constant pressure	$C_p(T)$	J/(kg·K)
Density	$\rho(p_A, T)$	kg/m <sup>3</sup>
Thermal conductivity	$k(T)$	W/(m·K)

### 3.3.3 Ice



*Ice*

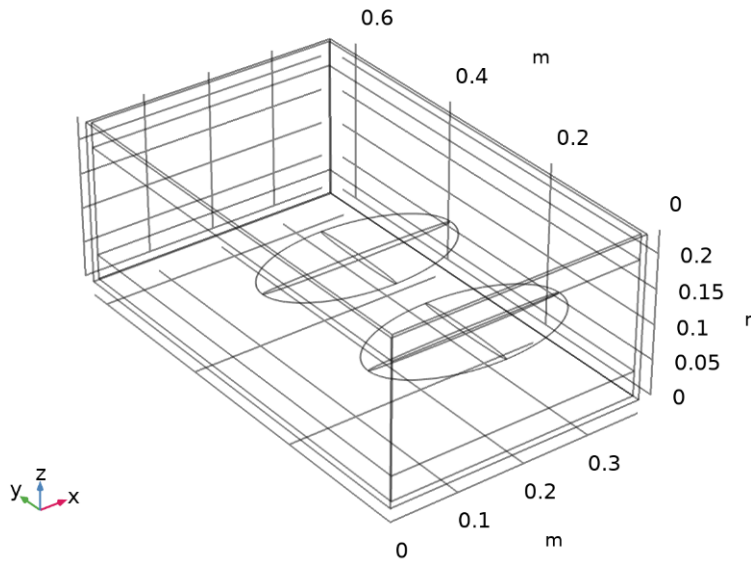
#### SELECTION

Geometric entity level	Domain
Selection	Domains 2, 4

#### MATERIAL PARAMETERS

Name	Value	Unit
Density	1000	kg/m <sup>3</sup>

### 3.3.4 Water, liquid

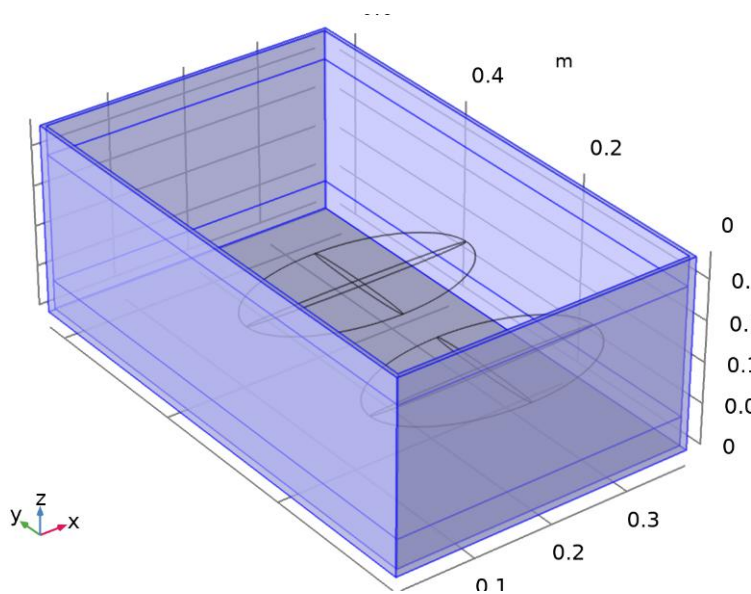


*Water, liquid*

#### SELECTION

Geometric entity level	Domain
Selection	No domains

### 3.3.5 HDPE (skin PE)



*HDPE (skin PE)*

#### SELECTION

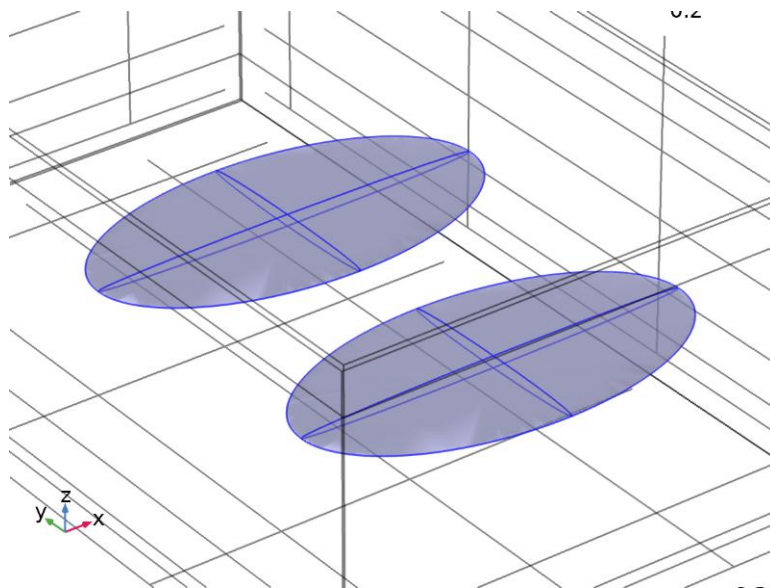
Geometric entity level	Domain
------------------------	--------

Selection	Domain 1
-----------	----------

#### MATERIAL PARAMETERS

Name	Value	Unit
Thermal conductivity	0.44	W/(m·K)
Density	930	kg/m <sup>3</sup>
Heat capacity at constant pressure	1.64*1000	J/(kg·K)

### 3.3.6 FAT



FAT

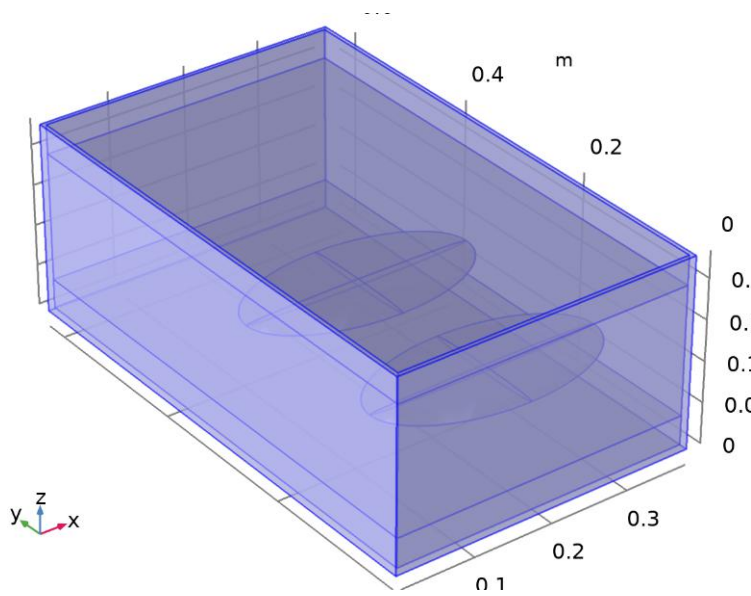
#### SELECTION

Geometric entity level	Domain
Selection	Domains 5-6

#### MATERIAL PARAMETERS

Name	Value	Unit
Density	1025	kg/m <sup>3</sup>
Heat capacity at constant pressure	3.5	J/(kg·K)
Thermal conductivity	0.41	W/(m·K)

### 3.4 HEAT TRANSFER IN POROUS MEDIA 2



*Heat Transfer in Porous Media 2*

#### SELECTION

Geometric entity level	Domain
Selection	Domains 1–6

#### EQUATIONS

$$(\rho c_p)_{\text{eff}} \frac{\partial T_2}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T_2 + \nabla \cdot \mathbf{q} = Q + Q_{\text{vd}}$$

$$\mathbf{q} = -k_{\text{eff}} \nabla T_2$$

#### 3.4.1 Interface settings

##### Discretization

#### SETTINGS

Description	Value
Temperature	Linear

##### Physical model

#### SETTINGS

Description	Value
Heat transfer in biological tissue	Off
Isothermal domain	Off
Heat transfer in porous media	On
Porous matrix model	Standard

Description	Value
Heat transfer in alloys	Off
Reference temperature	User defined
Reference temperature	293.15[K]

## FEATURES

Porous Medium 1
Initial Values 1
Thermal Insulation 1
Solid Foam
Initial Foam
ICE
Initial Values ICE
Solid fish
Initial Fish
Heat Flux 1

### 3.4.2 Porous Medium 1

#### EQUATIONS

$$(\rho c_p)_{\text{eff}} \frac{\partial T_2}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T_2 + \nabla \cdot \mathbf{q} = Q + Q_p + Q_{\text{vd}}$$

$$\mathbf{q} = -k_{\text{eff}} \nabla T_2$$

$$(\rho c_p)_{\text{eff}} = \theta_p \rho_p c_{p,p} + (1 - \theta_p) \rho c_p$$

$$k_{\text{eff}} = \theta_p k_p + (1 - \theta_p) k + k_{\text{disp}}$$

### 3.4.3 Thermal Insulation 1

#### EQUATIONS

$$-\mathbf{n} \cdot \mathbf{q} = 0$$

### 3.4.4 Solid Foam

#### EQUATIONS

$$\rho c_p \frac{\partial T_2}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T_2 + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$

$$\mathbf{q} = -k \nabla T_2$$

### 3.4.5 ICE

#### EQUATIONS

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$

$$\mathbf{q} = -k \nabla T$$

### Phase Change Material 1

#### EQUATIONS

$$\rho = \rho_{\text{solid}}$$

$$c_p = \theta_1 c_{p1} + \theta_2 c_{p2} + L_{1 \rightarrow 2} \frac{\partial \alpha_m}{\partial T}$$

$$\alpha_m = \frac{1}{2} \frac{\theta_2 - \theta_1}{\theta_1 + \theta_2}$$

$$k = \theta_1 k_1 + \theta_2 k_2$$

$$\theta_1 + \theta_2 = 1$$

### 3.4.6 Solid fish

#### EQUATIONS

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$

$$\mathbf{q} = -k \nabla T$$

### 3.4.7 Heat Flux 1

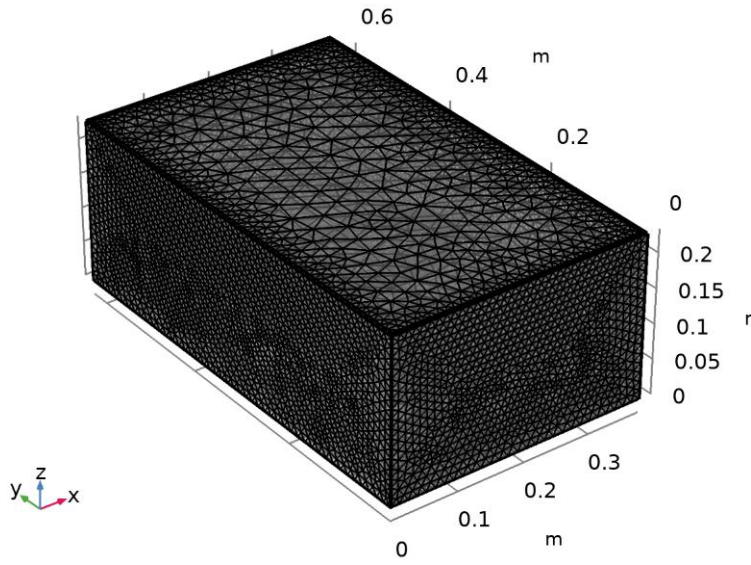
#### EQUATIONS

$$-\mathbf{n} \cdot \mathbf{q} = q_0$$

$$q_0 = h(T_{\text{ext}} - T)$$



### 3.5 MESH 9



Mesh 9

## 4 Study 3

### COMPUTATION INFORMATION

Computation time	1 h 20 min 22 s
CPU	Intel(R) Core(TM) i7-6500U CPU @ 2.50GHz, 2 cores
Operating system	Linux

### 4.1 TIME DEPENDENT

Times	Unit
range(0,0.5,24*5)	h

### STUDY SETTINGS

Description	Value
Include geometric nonlinearity	Off

### MESH SELECTION

Geometry	Mesh
mesh8	mesh8
mesh9	mesh9

### PHYSICS AND VARIABLES SELECTION

Physics interface	Discretization
Heat Transfer in Porous Media (ht)	physics
Heat Transfer in Porous Media 2 (ht2)	physics

### MESH SELECTION

Geometry	Mesh
Geometry 1 (geom1)	mesh8
Geometry 2 (geom2)	mesh9

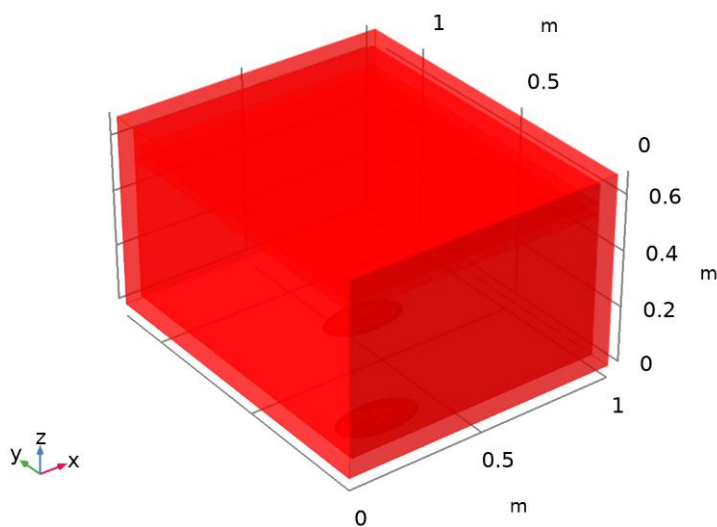
## 5 Results

### 5.1 DATA SETS

#### 5.1.1 Study 3/Solution 3 (1)

##### SOLUTION

Description	Value
Solution	Solution 3
Component	Save Point Geometry 1

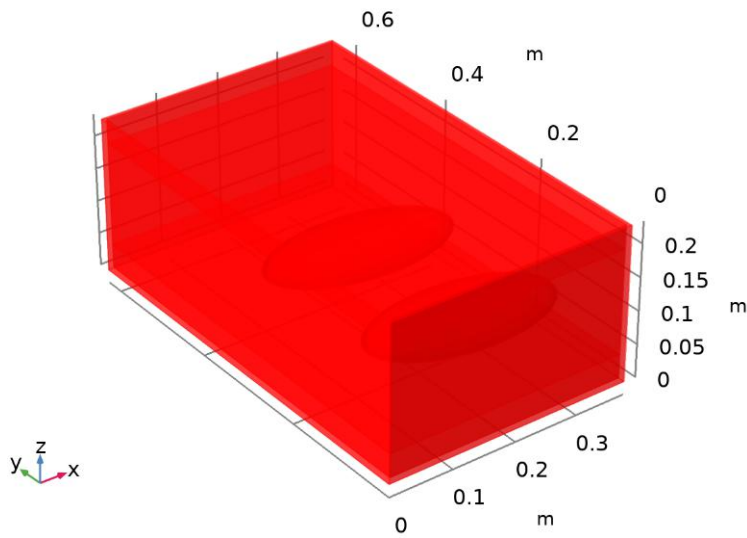


Data set: Study 3/Solution 3 (1)

#### 5.1.2 Study 3/Solution 3 (2)

##### SOLUTION

Description	Value
Solution	Solution 3
Component	Save Point Geometry 2

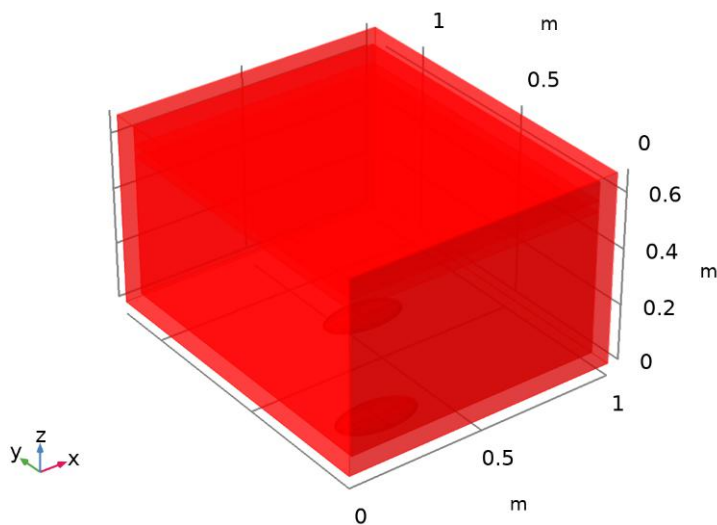


Data set: Study 3/Solution 3 (2)

### 5.1.3 Probe Solution 3

SOLUTION

Description	Value
Solution	Solution 3
Component	Save Point Geometry 1



Data set: Probe Solution 3

### 5.1.4 TUB-max surface middle fish

SELECTION

Geometric entity level	Boundary
Selection	Boundaries 27–34

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.5 TUB-max surface corner fish

#### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 19–25

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.6 TUB-Max

#### SELECTION

Geometric entity level	Domain
Selection	Domains 2, 5–6

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.7 TUB-Min

#### SELECTION

Geometric entity level	Domain
Selection	Domains 2, 5–6

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

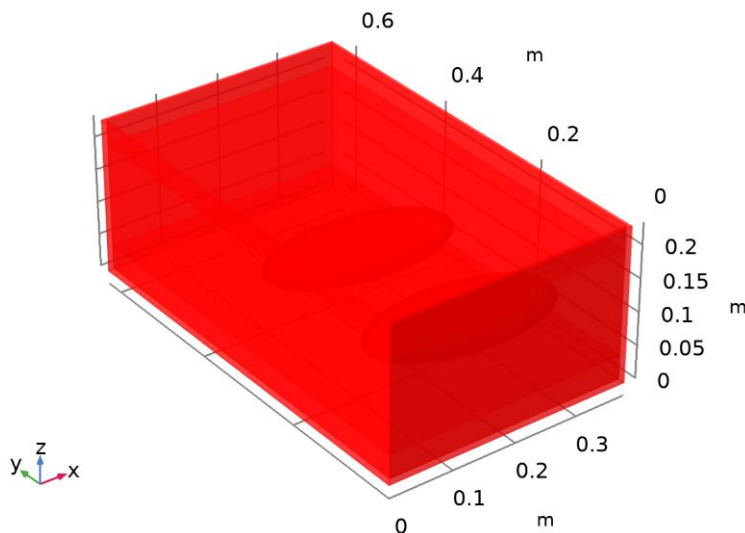
#### SETTINGS

Description	Value
Element refinement	4

### 5.1.8 Probe Solution 4

#### SOLUTION

Description	Value
Solution	Solution 3
Component	Save Point Geometry 2



Data set: Probe Solution 4

### 5.1.9 BFoam Average

#### SELECTION

Geometric entity level	Domain
Selection	Domain 1

#### DATA

Description	Value
-------------	-------

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.10 BIce Average

#### SELECTION

Geometric entity level	Domain
Selection	Domains 2, 4

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.11 % top ice average

#### SELECTION

Geometric entity level	Domain
Selection	Domain 4

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.12 % bottom ice average 1

#### SELECTION

Geometric entity level	Domain
Selection	Domain 2

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.13 Air Average

#### SELECTION

Geometric entity level	Domain
Selection	Domain 4

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.14 Ice Average temp

#### SELECTION

Geometric entity level	Domain
Selection	Domain 3

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>



## SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.15 %ice

#### SELECTION

Geometric entity level	Domain
Selection	Domain 3

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.16 Water Average

#### SELECTION

Geometric entity level	Domain
Selection	Domain 2

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.17 Water Maximum

#### SELECTION

Geometric entity level	Domain
------------------------	--------

Selection	Domain 2
-----------	----------

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.18 Foam average

#### SELECTION

Geometric entity level	Domain
Selection	Domain 1

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

### 5.1.19 Foam maximum boundary

#### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 1–5, 38

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.20 BFoam Maximum

#### SELECTION

Geometric entity level	Domain
Selection	Domain 1

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.21 BOX- max surface middle fish

#### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 23–26, 31–34

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.22 BOX- max surface corner

#### SELECTION

Geometric entity level	Boundary
Selection	Boundaries 19–22, 27–30

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.23 BOX-max

#### SELECTION

Geometric entity level	Domain
Selection	Domains 3, 5–6

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

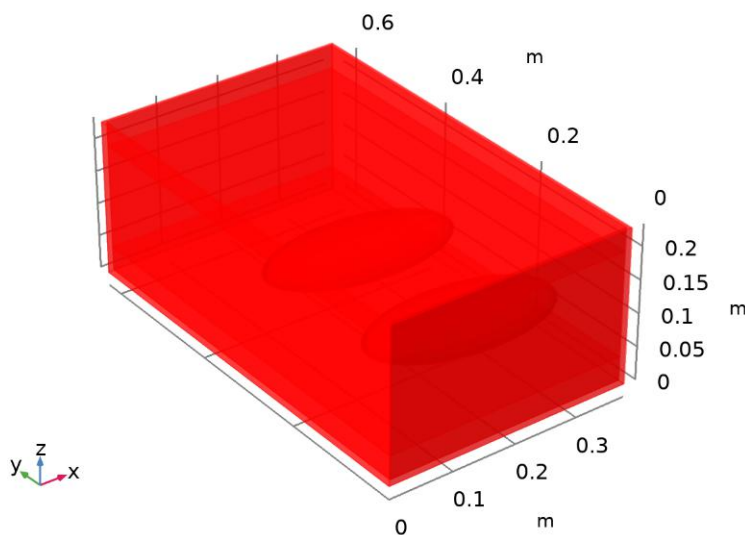
#### SETTINGS

Description	Value
Element refinement	4

### 5.1.24 Probe Solution 5

#### SOLUTION

Description	Value
Solution	Solution 3
Component	Save Point Geometry 2
Frame	Geometry (Xg, Yg, Zg)



Data set: Probe Solution 5

### 5.1.25 BOX-min

#### SELECTION

Geometric entity level	Domain
Selection	Domains 3, 5–6

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 5</a>

#### SETTINGS

Description	Value
Element refinement	4

### 5.1.26 Ice temp

#### SELECTION

Geometric entity level	Domain
Selection	Domains 2, 4

#### DATA

Description	Value
Data set	<a href="#">Probe Solution 4</a>

#### SETTINGS

Description	Value
Element refinement	4

## 5.2 DERIVED VALUES

### 5.2.1 TUB-max surface middle fish

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">TUB - max surface middle fish</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.2 TUB-max surface corner fish

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
-------------	-------

Description	Value
Data set	<a href="#">TUB - max surface corner fish</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.3 TUB-Max

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">TUB - Max</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.4 TUB-Min

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">TUB - Min</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.5 %ice

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">%ice</a>

#### EXPRESSIONS

Expression	Unit	Description
ht.theta1	1	Phase indicator, phase 1

## 5.2.6 Outside Temp

### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

### DATA

Description	Value
Data set	<a href="#">Probe Solution 3</a>

### EXPRESSIONS

Expression	Unit	Description
Tout(t)	degC	T outside fridge 1

## 5.2.7 BOX- max surface middle fish

### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

### DATA

Description	Value
Data set	<a href="#">BOX - max surface middle fish</a>

### EXPRESSIONS

Expression	Unit	Description
T2	degC	Temperature

## 5.2.8 BOX- max surface corner

### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

### DATA

Description	Value
Data set	<a href="#">BOX - max surface corner</a>

### EXPRESSIONS

Expression	Unit	Description
T2	degC	Temperature

### 5.2.9 BOX-max

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">BOX - max</a>

#### EXPRESSIONS

Expression	Unit	Description
T2	degC	Temperature

### 5.2.10 BOX-min

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">BOX - min</a>

#### EXPRESSIONS

Expression	Unit	Description
T2	degC	Temperature

### 5.2.11 % top ice average

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">% top ice average</a>

#### EXPRESSIONS

Expression	Unit	Description
ht2.theta1	1	Temperature

### 5.2.12 % bottom ice average 1

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------



#### DATA

Description	Value
Data set	<a href="#">% bottom ice average 1</a>

#### EXPRESSIONS

Expression	Unit	Description
ht2.theta1	1	Temperature

### 5.2.13 Air Average

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">Air Average</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.14 Ice Average temp

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">Ice Average temp</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.15 Water Average

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">Water Average</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.16 Water Maximum

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">Water Maximum</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.17 Foam average

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">Foam average</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.18 Foam maximum boundary

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">Foam maximum boundary</a>

#### EXPRESSIONS

Expression	Unit	Description
T	degC	Temperature

### 5.2.19 BFoam Average

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">BFoam Average</a>

#### EXPRESSIONS

Expression	Unit	Description
T2	degC	Temperature

### 5.2.20 BIce Average

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">BIce Average</a>

#### EXPRESSIONS

Expression	Unit	Description
T2	degC	Temperature

### 5.2.21 BFoam Maximum

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

#### DATA

Description	Value
Data set	<a href="#">BFoam Maximum</a>

#### EXPRESSIONS

Expression	Unit	Description
T2	degC	Temperature

### 5.2.22 Ice temp

#### OUTPUT

Evaluated in	Probe Table 1
--------------	---------------

DATA

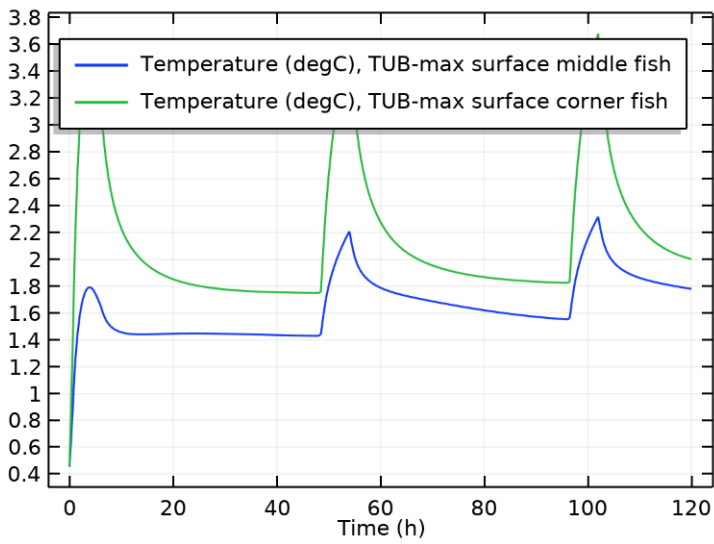
Description	Value
Data set	<a href="#">Ice temp</a>

EXPRESSIONS

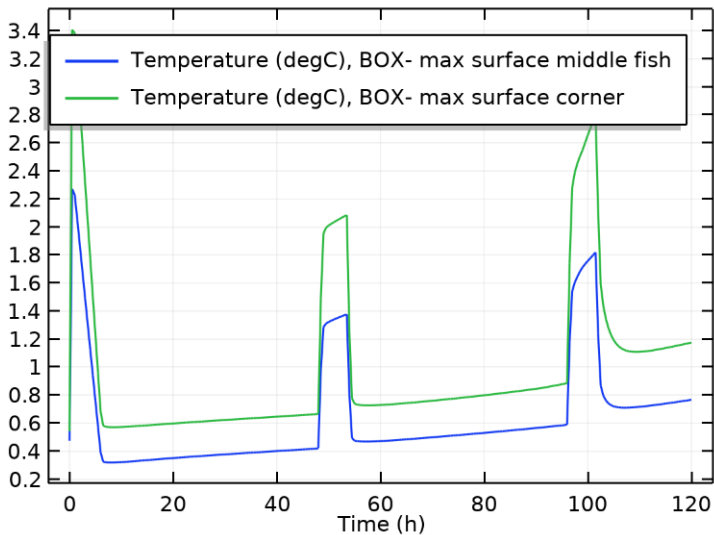
Expression	Unit	Description
T2	degC	Temperature

### 5.3 PLOT GROUPS

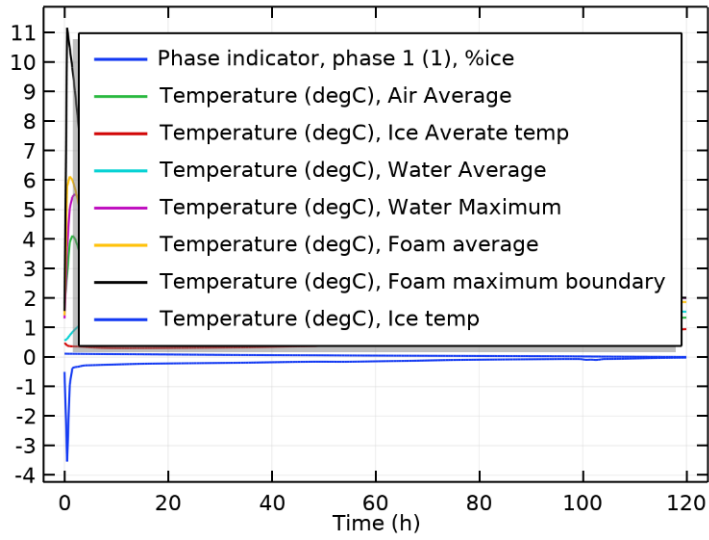
#### 5.3.1 TUB fish



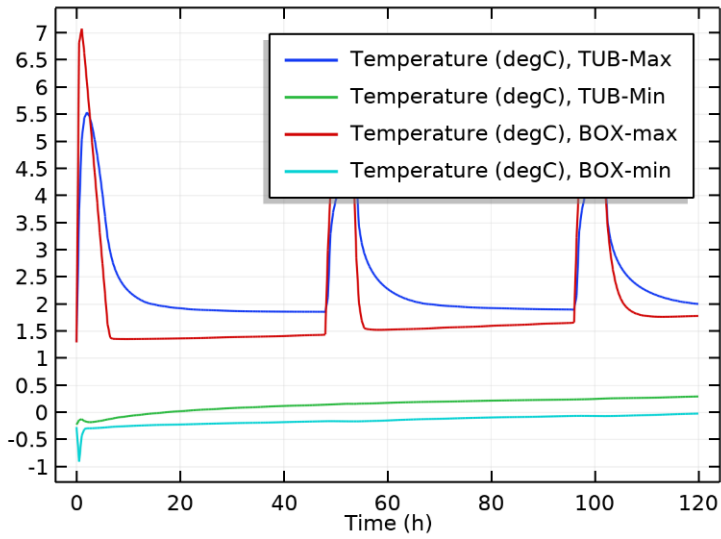
#### 5.3.2 BOX fish



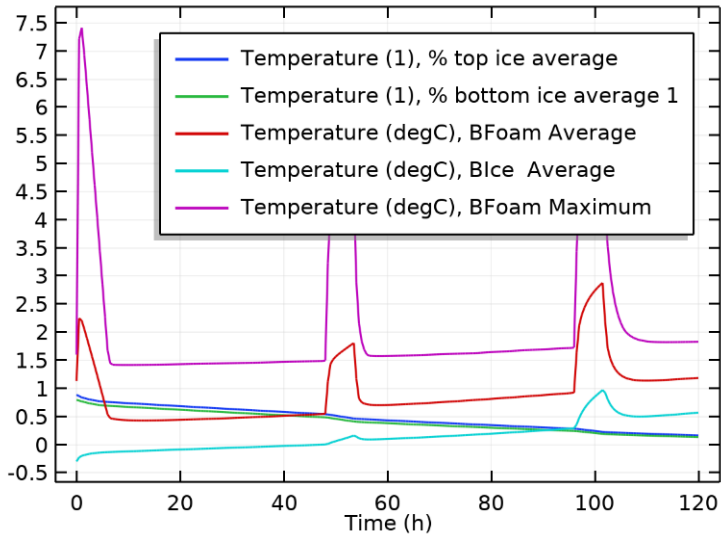
### 5.3.3 TUB Several



### 5.3.4 Comparison TUB-BOX



### 5.3.5 Probe Plot Group 15



### 5.3.6 Probe Plot Group 16

