1 Organizational Aspects

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Project:	**Building Automation System**
Subproject:	**Groupoffices-Thermal-Light-Security-Control**
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Responsible:	**SFB501-D1**
User:	**Team2**
Description:	Description of abstraction level and models for control

Version#	Date	Creators	Remarks
v1	20.11.95	Zimmermann	first ideas
v2.1	22.1.96	Queins	first adaption to the PB
v3	21.2.96	Queins	first fairly complete version
v3.1	19.3.96	Queins	Ventilation added

2 Problem Description

The problem is the control of temperature, humidity, air quality and light in a typical office. As an example the office 32/418 has been chosen. It is in the top floor of building 32 and faces south (front), has other offices left , right, and below, a hallway in the back and a roof on top.

3 Control Reference Model

3.1 Space

Classname:	Space		Superclass		
Description:					
Instances:					
State Variables	Name	Symbol	Function / Value	Dimension	Type
	current temperature	ϑ_{cur}	(f1)	$°C$	exp.

(f1) $\vartheta_{cur} = 20$

3.1.1 Indoor space

Classname:	IndoorSpace		Superclass	Space	
Description:	The indoor space is surrounded by the partition elements				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	PE heat flux	$\dot{Q}_f$	total heat flux	$\dot{Q}_{PE}$	ParttitonElements
Parameters	Name	Symbol	Range	Default	Dimension
	volume	V_r	5 ...500	75	m^3
State Variables	Name	Symbol	Function / Value	Dimension	Type
	total heat flux	$\dot{Q}_i$	(f2)	W	

heat gain because of the PE's:

(f2) $$\dot{Q}_i = \sum_{PE} \dot{Q}_f$$

3.1.1.1 Controlled Office

Classname:	ControlledOffice		Superclass	IndoorSpace	
Description:	room with 4 walls, floor, and ceiling. The south wall faces the outside.				
Instances:	32/418				
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	current temperature	ϑ_{cur}	measured temp.	ϑ_{out}	indoor temp. sensor
	radiator heat flux coefficient	$\dot{Q}_{\mathrm{HI0}}$	heat flux coefficient	$\dot{Q}_{\mathrm{HI0}}$	HeatingInstallation
	radiator transmittance	K_{HI}	total transmittance	K_{HI}	HeatingInstallation
	hot water flow slope	S	slope	S	HeatingInstallation
	light heat flux	$\dot{Q}_L$	total heat flux	$\dot{Q}_{\mathrm{L}}$	LightingInstallation
	person heat flux	$\dot{Q}_{Pers}$	heat production	H	Person
	equip. heat flux	$\dot{Q}_{Eq}$	total heat flux	$\dot{Q}_{Eq}$	Equipment
	radiation heat flux	$\dot{Q}_{Rad}$	radiation heat flux	$\dot{Q}_{Rad}$	WindowInstallation
	partition element transmittance	K_{PE}	total transmittance	K_{PE}	PartitionElement
	adjacent room temperature	ϑ_{adj}	back room temperature	ϑ_b	IndoorPartitionElement
	person present	PP	person present	PP	Person Detector
	outdoor temperature	ϑ_{e}	outdoor temp.	$\vartheta_{\mathrm{e,mea}}$	outdoor space
	ventilation air flow rate per person	$\dot{V}_{Pers}$	ventilation air flow rate per person	$\dot{V}_{Pers}$	Person
	ventilation air flow rate	$\dot{V}_{cur}$	air flow rate	$\dot{V}_{Win}$	WindowInstallation
Parameters	Name	Symbol	Range	Default	Dimension
	number of adjacent rooms	n_{adj}	1 - 4	3	none
	number of persons	n_{Pers}	0 - 10	1	none
	time constant	τ_{room}	60 .. 10000	2000	s

	Name	Symbol	Function / Value	Dimension	Type
State Variables	sum of constant heat flux	$\dot{Q}_{\mathrm{sum}}$	(f3)	W	
	sum of outdoor PE's transmittance	K_{ext}	(f4)	W/°C	
	sum of indoor PE's transmittance	K_{adj}	(f5)	W/°C	
	average adjacent room temperature	$\bar{\vartheta}_{adj}$	(f6)	°C	
	room temperature	ϑ_{i}	(f7)	°C	asy
			(f8)		asy, exp
			(f9)		dyn
	heatup time	T_{1_2}	(f10)	s	dyn
	air exchange rate	n_{air}	(f11)	h^{-1}	din
			(f12)		din
			(f13)		cal

the heat flux, which does not depends on ϑ_{e} or ϑ_i.

(f3) $$\dot{Q}_{sum} = \dot{Q}_{\mathrm{L}} + PP \cdot n_{\mathrm{Pers}} \cdot \dot{Q}_{\mathrm{Pers}} + \dot{Q}_{Eq} + \dot{Q}_{Rad} + \dot{Q}_{HI0}$$

the sum of the K's of the outdoor partition elements:

(f4) $$K_{ext} = \sum_{outdoorPE\mathrm{s}} K_{PE}$$

the sum of the K's of the indoor partition elements:

(f5) $$K_{adj} = \sum_{indoorPE\mathrm{s}} K_{PE}$$

the average of the temperature in the adjacent rooms:

(f6) $$\bar{\vartheta}_{adj} = \frac{\sum_{indoorPE\mathrm{s}} \vartheta_{adj}}{n_{adj}}$$

the most reachable (with a fully opened radiator valve) temperature, correct:

(f7) $$\vartheta_{\mathrm{i,asy}} = \frac{\dot{Q}_{sum} + (K_{\mathrm{ext}} - S \cdot K_{\mathrm{HI}}) \cdot \vartheta_{\mathrm{e}} + K_{\mathrm{adj}} \cdot \bar{\vartheta}_{\mathrm{adj}}}{K_{\mathrm{ext}} + K_{\mathrm{adj}} + K_{\mathrm{HI}}}$$

the highest reachable temperature, determined by an experiment with closed windows and doors and $\dot{Q}_{\mathrm{sum}} = \dot{Q}_{\mathrm{HI0}}$:

(f8) $$\vartheta_{i,\,asy} = 23$$

The temperature, which can be reached in time t, starting from ϑ_{cur}:

(f9) $$\vartheta_{i,\,dyn}(t) = \vartheta_{\mathrm{i,asy}} - (\vartheta_{\mathrm{i,asy}} - \vartheta_{cur}) \cdot e^{-t/\tau_{\mathrm{room}}}$$

correct for $t < \tau_{room}$.

The time needed to increase the temperature from $\vartheta_{\mathrm{i,1}}$ to $\vartheta_{\mathrm{i,2}}$:

(f10) $$T_{1\_2} = \tau_{\mathrm{room}} \cdot \ln\left(\frac{\vartheta_{\mathrm{i,\,asy}} - \vartheta_{\mathrm{i,\,1}}}{\vartheta_{\mathrm{i,\,asy}} - \vartheta_{\mathrm{i,\,2}}}\right)$$

(good approximation only as long as log < 1.5)

the din-norm for the air exchange rate

(f11) $$n_{air} = 0.5$$

another din-norm for the air exchange rate

(f12) $$n_{air} = n_{Pers} \cdot \dot{V}_{Pers} / V_r$$

the current air exchange rate

(f13) $$n_{air} = \dot{V}_{cur} / V_r$$

3.1.2 Outdoor space

Classname:	OutdoorSpace		Superclass	Space	
Description:					
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	current temperature	ϑ_{cur}	measured temp.	ϑ_{out}	outdoor temp. sensor
	current rain	$\Re_{\mathrm{cur}}$	measured rain	$\Re_{\mathrm{out}}$	outdoor rain sensor
Parameters	Name	Symbol	Range	Default	Dimension
	design temperature	$\vartheta_{e,\, des}$	-50 - 0	-12	$°\mathrm{C}$
State Variables	Name	Symbol	Function / Value	Dimension	Type
	radiation on vertical surface	E_{V}	(f14)	Wm^{-2}	

(f14)

3.2 Partition Element

Classname:	PartitionElement		Superclass		
Description:	A partition element PE has the two faces “front” and “back”. The front always faces the indoor room or the controlled office. All flows are directed from the PE.				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	front room temp.	ϑ_f	temperature	ϑ	indoor space
	back room temp.	ϑ_b	temperature.	ϑ	space
Parameters	Name	Symbol	Range	Default	Dimension
	average thermal transmittance	k_m	0 - 2	1	$\mathrm{Wm}^{-2}\mathrm{K}^{-1}$
	total area	A	2 - 20	12	m^2
State Var.	Name	Symbol	Function / Value	Dimension	Type
	total transmittance	K_{PE}	(f15)	W/°C	
	total heat flux	$\dot{Q}_{PE}$	(f16)	W	

(f15) $$K_{PE} = A \cdot k_m$$

(f16) $$\dot{Q}_{PE} = K_{PE} \cdot (\vartheta_b - \vartheta_f)$$

3.2.1 Indoor Partition Element

Classname:	IndoorPartitionElement		Superclass	PartitionElement	
Description:	The Indoor PE separates in this context the controlledOffice (face-side) from the other rooms. Each Indoor PE consists of a door o the adjacent rooms.				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	door transmittance	K_{Door}	total transmittance	K_{Door}	door installation
Parameters	Name	Symbol	Range	Default	Dimension
	average thermal transmittance	k_m	0 - 2	1	$\mathrm{Wm}^{-2}\mathrm{K}^{-1}$
State Var.	Name	Symbol	Function / Value	Dimension	Type
	total transmittance	K_{PE}	(f17)	W/°C	

(f17) $$K_{PE} = K_{PE,\,PartitionElement} + K_{Door}$$

3.2.2 Outdoor Partition Element

Classname:	OutdoorPartitionElement		Superclass	PartitionElement	
Description:	The Outdoor PE separates in this context the controlledOffice (face-side) from the outside space. Each Outdoor PE consists of one or more windows.				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	window transmittance	K_{Win}	total transmittance	K_{Win}	windowInstallation
Parameters	Name	Symbol	Range	Default	Dimension
	average thermal transmittance	k_m	0 - 2	1.3	$\mathrm{Wm}^{-2}\mathrm{K}^{-1}$
State Var.	Name	Symbol	Function / Value	Dimension	Type
	total transmittance	K_{PE}	(f18)	W/°C	

(f18) $$K_{PE} = K_{PE,\, PartitionElement} + K_{Win}$$

3.3 Heating Installation

Classname:	HeatingInstallation		Superclass	heat source	
Description:	Installed radiators and valves				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	radiator temperature	ϑ_R	measured temp.	ϑ_{out}	radiator temp. sensor
	new valve value	U_V	output	O	heating selector
	outdoor temperature	ϑ_e	measured temp.	ϑ_{out}	outdoor space
	room temperature	ϑ_i	room temperature	$\vartheta_{i,\,act}$	contr. office
Parameters	Name	Symbol	Range	Default	Dimension
	start temperature	ϑ_0	0 - 90	25	°C
	standard heat output	$\dot{Q}_{HIN}$		4000	W
	slope	S	0 - 10	2	none
State Var.	Name	Symbol	Function / Value	Dimension	Type
	temperature coefficient	ϑ_k	(f19)	°C	
	hot water flow temperature	ϑ_V	(f20)	°C	dyn.
	total transmittance	K_{HI}	(f21)	W/°C	
	heat flux coefficient	$\dot{Q}_{HI0}$	(f22)	W	max.
	actual heat flux	$\dot{Q}_{HI}$	(f23), (f24)	W	dyn.

(f19) $$\vartheta_K = \vartheta_0 + S \cdot 20°C$$

(f20) $$\vartheta_v(\vartheta_e) = \begin{cases} \vartheta_0 + S \cdot (20°C - \vartheta_e) \text{ for } (\vartheta_e < 20°C) \\ 20°C \text{ for } (\vartheta_e \geq 20°C) \end{cases}$$

(f21) $$K_{HI} = \dot{Q}_{HIN} / 70°C$$

the constant heat flux:

(f22) $$\dot{Q}_{HI0} = K_{HI} \cdot \vartheta_k$$

the total heat flux with the assumption of an fully opened valve:

(f23) $$\dot{Q}_{HI} = K_{HI} \cdot (\vartheta_v - \vartheta_i)$$

the total heat flux with the assumption of an fully opened valve:

(f24) $$\dot{Q}_{\mathrm{HI}} = \dot{Q}_{\mathrm{HI0}} - K_{\mathrm{HI}} \cdot (S \cdot \vartheta_e + \vartheta_i)$$

3.4 Window Installation

Classname:	WindowInstallation		Superclass		
Description:	The window installation consists of three pairs of an upper and a lower window. The upper window can be controlled by setting $U_{UWin,\,new}$				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	current lower window value	$U_{LWin,\,cur}$			Lower Window sensor
	current upper window value	$U_{UWin,\,cur}$			Upper Window sensor
	new upper window value	$U_{UWin,\,new}$			control system
	indoor temp.	ϑ_i	current temperature	ϑ	indoor space
	outdoor temp.	ϑ_e	current temperature	ϑ	outdoor space
	rad. on vert. surface	E_{V}	rad. on vert. surface	E_{V}	outdoor space
Constants	Name	Symbol	Value	Dimension	
	heat capacitance per volume, air	c_{va}	1200	Wsm^{-3}	
Parameters	Name	Symbol	Range	Default	Dimension
	transmission ratio	g	0.7 - 0,9	0,8	none
	joint length	l_{j}		20	m
	joint permeability coeff.	a_{j}		0.6	$\mathrm{m^2h^{-1}Pa^{-2/3}}$
	building coeff.	H		1	
	ventilation form factor, upper sash	$c_{\mathrm{o,UWin}}$		0.015	$m^{-1/2}K^{1/2}s^{-1}$
	ventilation form factor, lower sash	$c_{\mathrm{o,LWin}}$		0.04	$m^{-\frac{1}{2}}K^{\frac{1}{2}}s^{-1}$
	upper window area	A_{UWin}	0.1 - 1	0.5	m^2
	upper window height	h_{UWin}	0.1 - 1	0.5	m
	lower window area	A_{LWin}	0.5 - 2	1	m^2
	lower window height	h_{LWin}	0.1 - 2	1	m
	height above building center	y	1 - 30	5	m

	Name	Symbol	Function / Value	Dimension	Type
State Var.	total area	A	(f25)	m^2	
	radiation heat flux	$\dot{Q}_{Rad}$	(f26)	W	
	thermal pressure difference (closed windows)	Δp_{thc}	(f27)	Pa	
	infiltration coeff.	c_{inf}	(f28)	W/°C	
	ventilation coeff. for upper window	$c_{\mathrm{V,UWin}}$	(f29)	m^3h^{-1}	
	ventilation coeff. for lower window	$c_{\mathrm{V,LWin}}$	(f30)	m^3h^{-1}	
	air flow rate	$\dot{V}_{Win}$	(f31)	m^3s^{-1}	
	ventilation heat flux	$\dot{Q}_V$	(f32)	W	
	total heat flux	$\dot{Q}_{Win}$	(f33)	W	

(f25) $$A = A_{UWin} + A_{LWin}$$

(f26) $$\dot{Q}_{Rad} = E_{\mathrm{v}} \cdot A \cdot g$$

(f27) $$\Delta p_{thc} = 0.045 \cdot y \cdot (\vartheta_i - \vartheta_e)$$

(f28) $$c_{\mathrm{inf}} = a_j \cdot l_{\mathrm{j}} \cdot \Delta p^{2/3}{}_{thc}$$

(f29) $$c_{\mathrm{V,UWin}} = c_{0,\,UWin} \cdot A_{UWin} \cdot \sqrt{h_{UWin} \cdot |\vartheta_i - \vartheta_e|}$$

(f30) $$c_{\mathrm{V,LWin}} = c_{0,\,LWin} \cdot A_{LWin} \cdot \sqrt{h_{LWin} \cdot |\vartheta_i - \vartheta_e|}$$

(f31) $$\dot{V}_{Win} = c_{inf} + U_{\mathrm{UWin,cur}} \cdot c_{\mathrm{V,UWin}} + U_{L\mathrm{Win,cur}} \cdot c_{V,\mathrm{LWin}}$$

(f32) $$\dot{Q}_V = (\vartheta_i - \vartheta_e) \cdot c_{va} \cdot \dot{V}_{Win}$$

(f33) $$\dot{Q}_{Win} = \dot{Q}_V + \dot{Q}_{Rad}$$

3.5 Door Installation

Classname:	windowInstallation		Superclass		
Description:					
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	current door value	$U_{Door, cur}$			Door sensor
	front temp.	ϑ_f		ϑ	indoor space
	back temp.	ϑ_b		ϑ	space
Constants	Name	Symbol	Value	Dimension	
	heat capacitance per volume, air	c_{va}	1200	Wsm^{-3}	
Parameters	Name	Symbol	Range	Default	Dimension
	transmission ratio	g	0.7 - 0,9	0,8	none
	joint length	l_j		7	m
	joint permeability coeff.	a_j		0.5	$m^3m^{-1}h^{-1}Pa^{-2/3}$
	building coeff.	H		1	
	ventilation form factor	c_o		????	WKm^{-3}
	door area	A_{Door}	2 - 6	2	m^2
	door height	h_{UWin}	2 - 4	2	m
State Var.	Name	Symbol	Function / Value	Dimension	Type
	infiltration coeff.	c_{inf}	(f28)	W/°C	
	total transmittance	K_{Door}	(f35)	W/°C	
	total heat flux	$\dot{Q}_{Door}$	(f36)	W	

(f34) $$c_{inf} = a_j \cdot l_j \cdot H$$

(f35) $$K_{Door} = c_{va} \cdot (c_{inf} + c_0 \cdot (U_{Door,cur} \cdot h_{LWin} \cdot A_{LWin}))$$

(f36) $$\dot{Q}_{Door} = (\vartheta_f - \vartheta_b) K_{Door}$$

3.6 PID-Control

Classname:	PIDControl		Superclass		
Description:	The digital pid-controller to realize a closed-looped-control.				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	actual setting	r	n.a.	n.a.	n.a.
	nominal value	w	n.a.	n.a.	n.a.
	actual time	t_{act}	global time	t	central timer
Parameters	Name	Symbol	Range	Default	Dimension
	parameter1	b_0	-1000 - 1000	n.a.	n.a.
	parameter2	a_1	-1000 - 1000	n.a.	none
	parameter3	b_1	-1000 - 1000	n.a.	n.a.
	parameter4	a_2	-1000 - 1000	n.a.	none
	parameter5	b_2	-1000 - 1000	n.a.	n.a.
	time period	τ	0.1 - 3600	n.a.	s
State Variables	Name	Symbol	Function	Dimension	Type
	time clicks	tc	(f37)	none	
	difference	e_{tc}	(f38)	n.a.	
	new setting	U_{tc}	(f39)	n.a.	

(f37) $$tc = \frac{t_{act}}{\tau}$$

the difference at time step k:

(f38) $$e_{tc} = w - r$$

the value at time step k:

(f39) $$U_{tc} = a_1 U_{tc-1} + a_2 U_{tc-2} + b_0 e_{tc} + b_1 e_{tc-1} + b_2 e_{tc-2}$$

3.6.1 Heating-Control

Classname:	HeatingControl		Superclass	PIDControl	
Description:	The controller to realize a closed-looped-control for controlling the room temperature.				
Instances:	heating controller				
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	actual value	r	room temperature	ϑ_i	controlled office
	nominal value	w	nominal temperature	$\vartheta_{Room,\ nom}$	temperature control
Parameters	Name	Symbol	Range	Default	Dimension
	paramter1	b_0		24	$V/°C$
	paramter2	a_1		0	
	paramter3	b_1		10	$V/°C$
	paramter4	a_2		0	
	paramter5	b_2		0	$V/°C$
	time period	τ	1 - 3600	60	
State Variables	Name	Symbol	Function	Dimension	Type
	difference	e_{tc}	$°C$	(f38)	
	new setting	U_{tc}	V	(f39)	

3.6.2 Radiator-Control

Classname:	RadiatorControl		Superclass	PIDControl	
Description:	The controller to realize a closed-looped-control for controlling the radiator temperature.				
Instances:	radiator controller				
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	actual value	r	radiator temperature	ϑ_R	heating installation
	nominal value	w	nominal temperature	$\vartheta_{Rad, nom}$	temperature control
Parameters	Superclass Name	Superclass Symbol	Range	Default	Dimension
	paramter1	b_0		24	$V/°C$
	paramter2	a_1		0	
	paramter3	b_1		10	$V/°C$
	paramter4	a_2		0	
	paramter5	b_2		0	$V/°C$
	time period	τ	10 - 3600	600	
State Variables	Superclass Name	Superclass Symbol	Function	Dimension	Type
	difference	e_{tc}		°C	
	new setting	U_{tc}		V	

3.7 Heating Selector

Classname:	HeatingSelector		Superclass		
Description:	A Multiplexer with 4 inputs, one select input and one output.				
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
	Input 1	I_1	actual value	U_k	heating control
	Input 2	I_2	actual value	U_k	radiator control
	Input 3	I_3	user value	U_{User}	temperature control
	Input 4	I_4	closing value	U_{Close}	temperature control
	Select	S	heating selector	$S_{Heating}$	temperature control
State Var.	Name	Symbol	Function / Value	Dimension	Type
	Output	O	(f40)		

(f40) O = case S of 1: I1
2: I2
3: I3
4: I4

3.8 Equipment

Classname:	equipment		Superclass		
Description:					
Instances:					
Parameters	Name	Symbol	Range	Default	Dimension
	electric power	P_{Eq}	0 .. 2000	100	W
	equipment control	U_{Eq}	0, 1	0	
State Var.	Name	Symbol	Function / Value	Dimension	Type
	total heat flux	$\dot{Q}_{Eq}$	(f41)	W	

(f41) $\dot{Q}_{Eq} = P_{eq} \cdot U_{Eq}$

3.9 Person

Classname:	Person		Superclass		
Description:					
Instances:					
Parameters	Name	Symbol	Range	Default	Dimension
	person heat production	H	50 .. 150	100	W
	ventilation air flow rate per person	$\dot{V}$	10-30	15	din

3.10 Local Climate

Classname:	local climat		Superclass	outdoor climat	
Description:					
Instances:					
Interface Variables	Int. Name	Int. Symbol	Ext. Name	Ext. Symbol	Ext. Object
Constants	Name	Symbol	Value	Dimension	
	solar constant	E_0	1390	Wm^{-2}	
Parameters	Name	Symbol	Range	Default	Dimension
	month	m	1 - 12		
	time of day	t_d	0 - 24	15	h
	average outdoor temperature	ϑ_{em}	-12 - 24	24	°C
	temperature variation	Θ_e	4 - 8	8	°C
	lattitude	φ		49.45	°
	longitude	λ		-7.77	°
Variables	solar altitude angle	h			°
State Var.	Name	Symbol	Function / Value	Dimension	Type
	outdoor temperature sunny day	ϑ_{esun}	(f42)		
	outdoor design temperature		-12		design

Simplified temperature on a sunny day:

(f42) $$\vartheta_{em} + \Theta_e \cdot \cos\left(2\pi \cdot \frac{(t_d - 15\mathrm{h})}{24\mathrm{h}}\right)$$