

# Building simulation analysis for smartengine

Case studies in cellular offices and open-plan offices

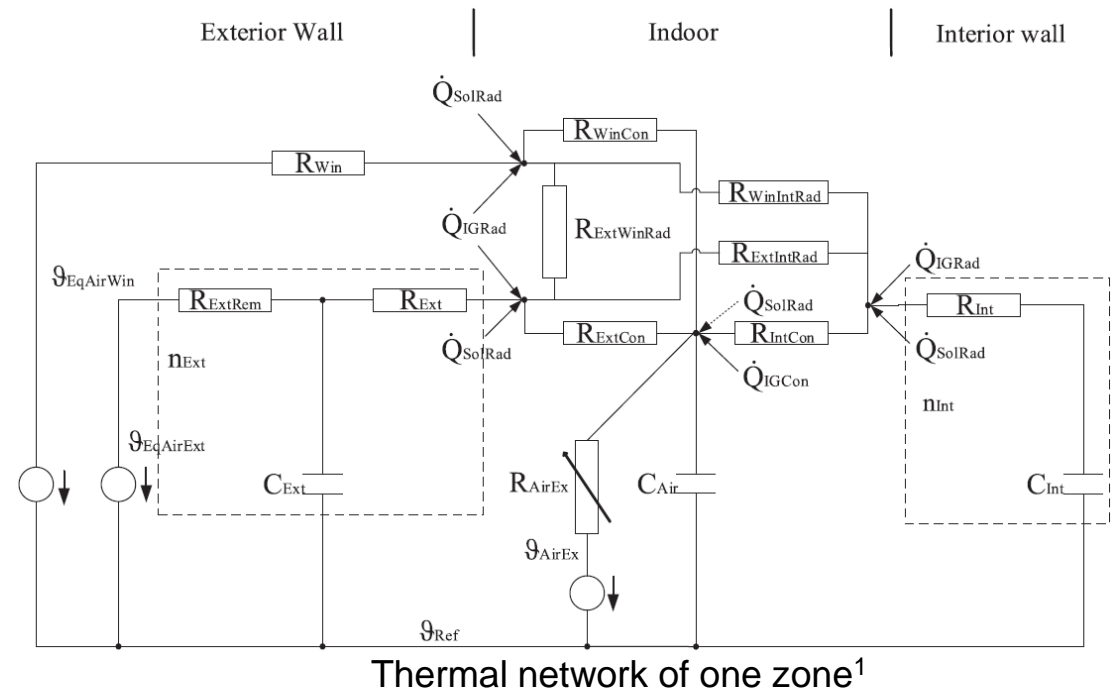
# Motivation

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- Potential of the demand-oriented mechanical ventilation and lighting in non-residential buildings
  - ≡ Achieving energy-saving
  - ≡ Without compromise of thermal comfort
  
- Analysis of applying smartengine + building automation in modern office buildings
  - ≡ Through building simulation methods
  - ≡ Case I: 4 cellular offices
  - ≡ Case II: 4 open-plan offices

# Introduction of the building model for the thermal simulation

- A simplified multi-zone building model in the modeling language Modelica
  - ≡ Building geometry with consideration of orientation and building physics
    - = Conversion to thermal resistances (R) and capacities (C) via the tool TEASER<sup>1</sup>, based on the German standard VDI 6007<sup>2</sup>
  - ≡ Model for internal gains (people, machine, lighting): intensity with time profiles
  - ≡ Homogenous air nodes for a single zone
  - ≡ Consideration of heat convection as well as heat radiation



<sup>1</sup> TEASER: an open tool for urban energy modelling of building stocks. P. Remmen, M. Lauster, M. Mans, M. Fuchs, T. Osterhage, D. Müller. Journal of Building Performance Simulation, February 2017

<sup>2</sup> VDI 6007 Part 1 – Calculation of transient thermal response of rooms and buildings – Modelling of rooms. The Association of German Engineers (VDI). June 2015.

# Input Parameters – Cellular Office

Variants	Reference Office North, East, South and West	smartengine-variant Office North, East, South and West
Weather data		
City	Düsseldorf	Düsseldorf
Building physics		
Building geometries	The same as parameters from ROM	The same as parameters from ROM
U-value etc.	The same as parameters from ROM	The same as parameters from ROM
F <sub>c</sub> -value	0.25	0.25



Bildquelle: Auszug\_Ergebnisse\_smartengine-plus-GA.pdf

# Input Parameters – Cellular Office

Variants	Reference Office North, East, South and West	smartengine-variant Office North, East, South and West
Heating and cooling		
Room temp. set point	21 °C: for heating 25.5 °C: for cooling	21 °C: for heating 25.5 °C: for cooling
Ventilation		
Supply air temperature	21 °C: when outdoor temp. < 15 °C 18 °C: when outdoor temp. > 26 °C Gliding: when outdoor temp. between 15 & 26 °C	21 °C: when outdoor temp. < 15 °C 18 °C: when outdoor temp. > 26 °C Gliding: when outdoor temp. between 15 & 26 °C
Infiltration	0.1 h <sup>-1</sup>	0.1 h <sup>-1</sup>
Volume flow of AHU	Constant in working hours 6.00 m <sup>3</sup> /(m <sup>2</sup> h)	Variable in working hours Max. 6.00 m <sup>3</sup> /(m <sup>2</sup> h)
Efficiency of heat recovery	0.68	0.68
dp total	1820 Pa	variable
Elec. efficiency of AHU	0.631	variable
Internal gains		
People	13.80 W/m <sup>2</sup> + time profile	13.80 W/m <sup>2</sup> + time profile
Machines	16.60 W/m <sup>2</sup> + time profile	16.60 W/m <sup>2</sup> + time profile
Lighting	5.43 W/m <sup>2</sup> + on/off-profile	5.43 W/m <sup>2</sup> + lighting control + time profile

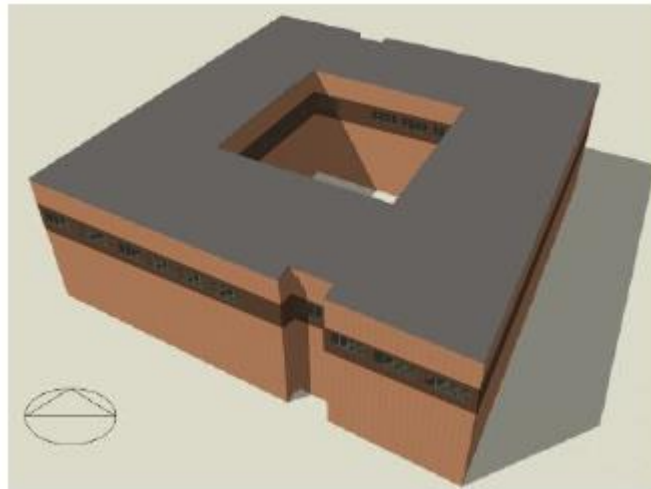
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**All the time profiles including volume flow of AHU begin with a Sunday.**

# Input Parameters – Open-plan Office

Variants	Reference Office NO, NW, SO, SW	smartengine-variant Office NO, NW, SO, SW
Weather data		
City	Erlangen	Erlangen
Building physics		
Building geometries	The same as parameters from ROM	The same as parameters from ROM
U-value etc.	The same as parameters from ROM	The same as parameters from ROM
F <sub>c</sub> -value	0.25	0.25



Bildquelle: Auszug\_Ergebnisse\_smartengine-plus-GA.pdf

# Input Parameters – Open-plan Office

Variants	Reference Office NO, NW, SO, SW	smartengine-variant Office NO, NW, SO, SW
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Infiltration	0.1 h <sup>-1</sup>	0.1 h <sup>-1</sup>
Volume flow of AHU	Constant in working hours 4.89 m <sup>3</sup> /(m <sup>2</sup> h)	Variable in working hours Max. 4.89 m <sup>3</sup> /(m <sup>2</sup> h)
Efficiency of heat recovery	0.68	0.68
dp total	1820 Pa	variable
Elec. efficiency of AHU	0.631	variable
Internal gains		
People	9.50 W/m <sup>2</sup> + time profile	9.50 W/m <sup>2</sup> + time profile
Machine	9.50 W/m <sup>2</sup> + time profile	9.50 W/m <sup>2</sup> + time profile
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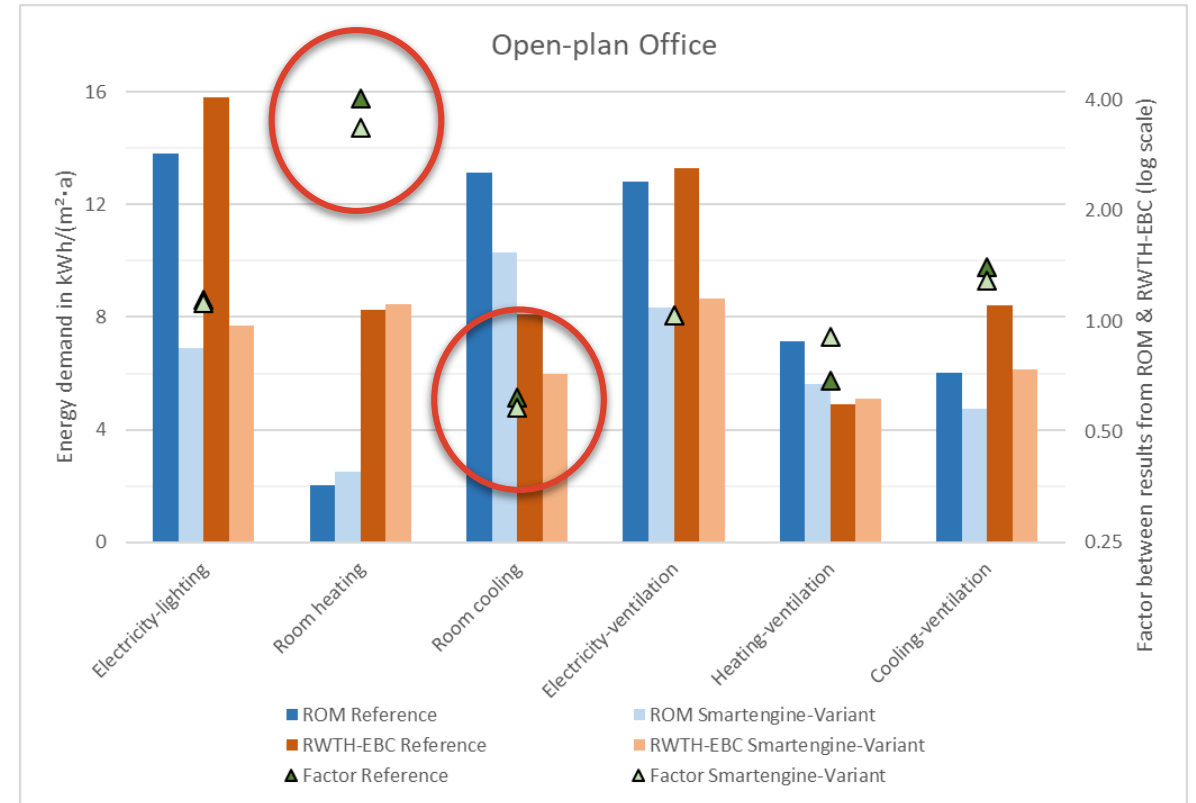
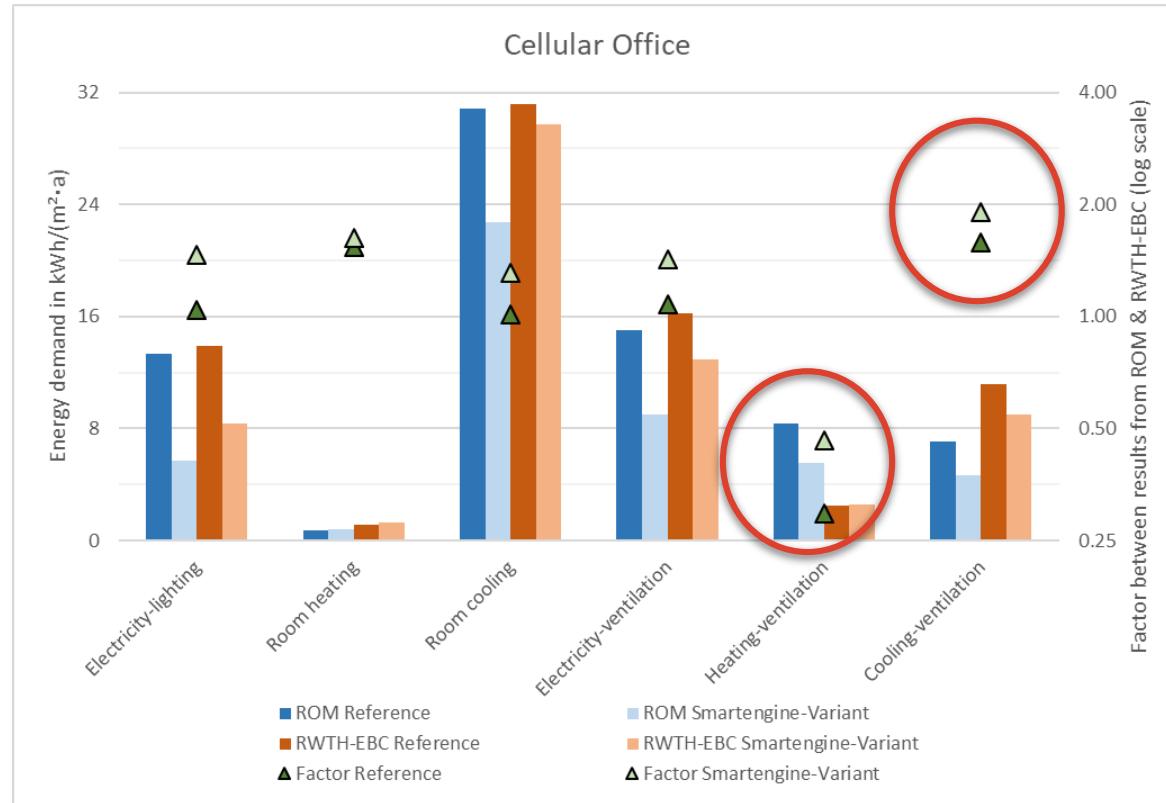
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**All the time profiles including volume flow of AHU begin with a Monday.**

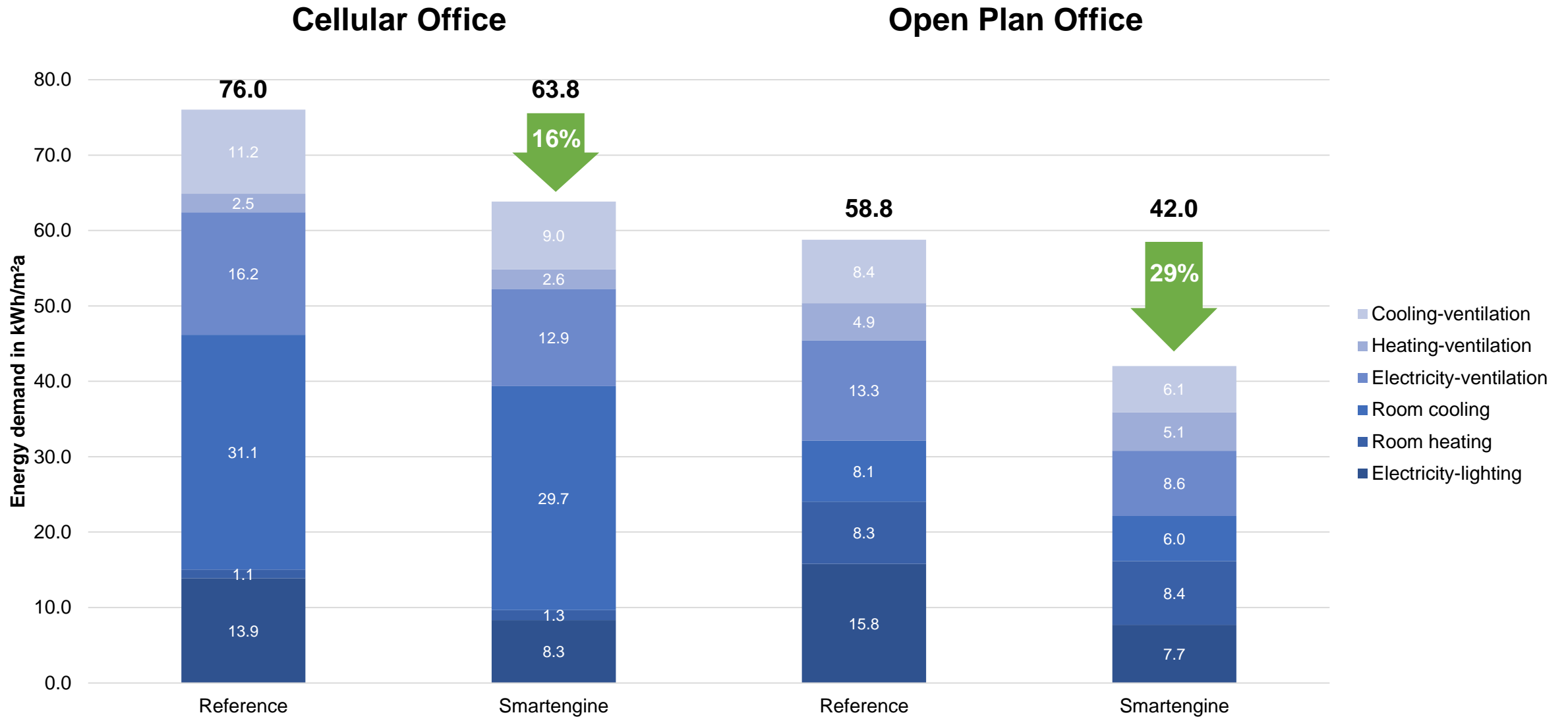
# Results & Comparison of RWTH and ROM studies

## ■ Energy demand

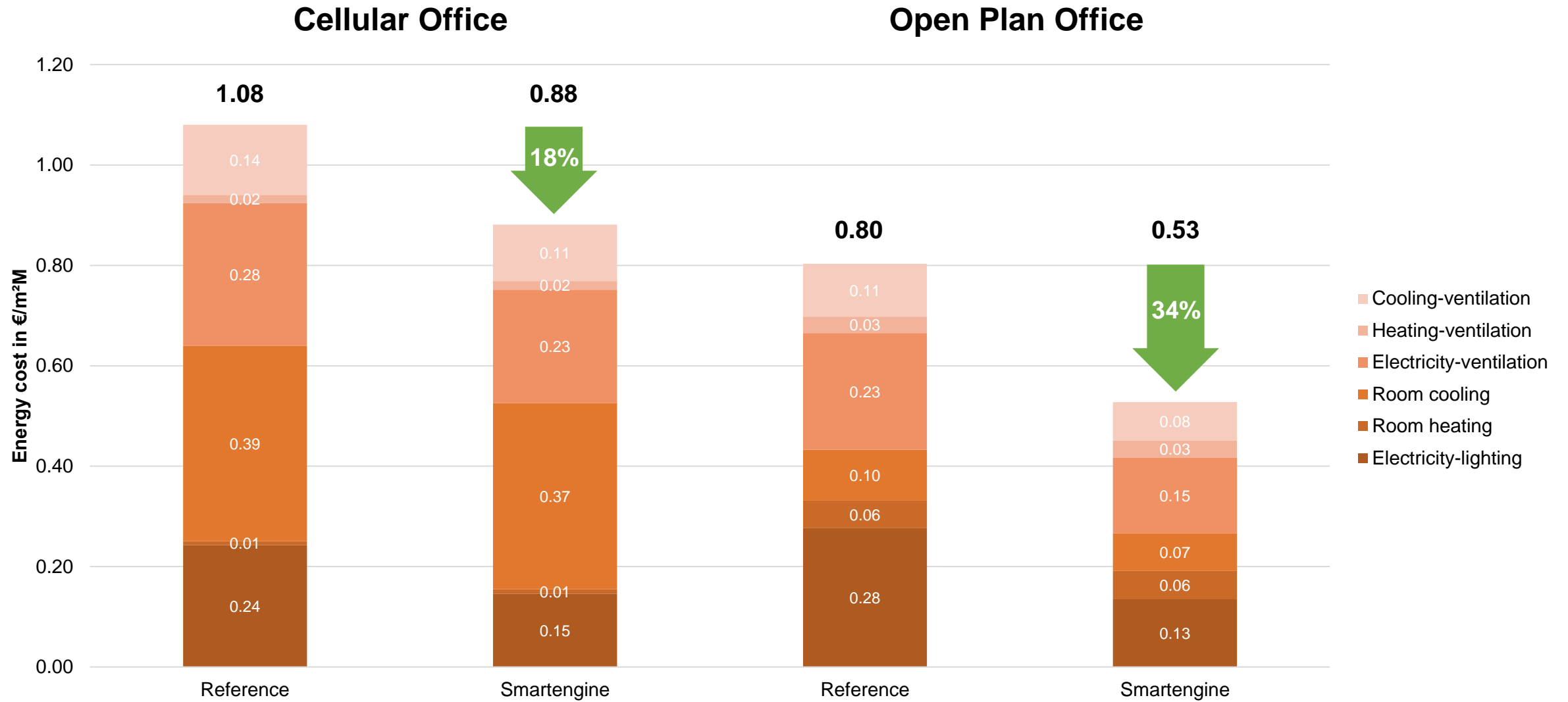


Data of ROM from Auszug\_Ergebnisse\_smartengine-plus-GA.pdf, date: 21.10.2019

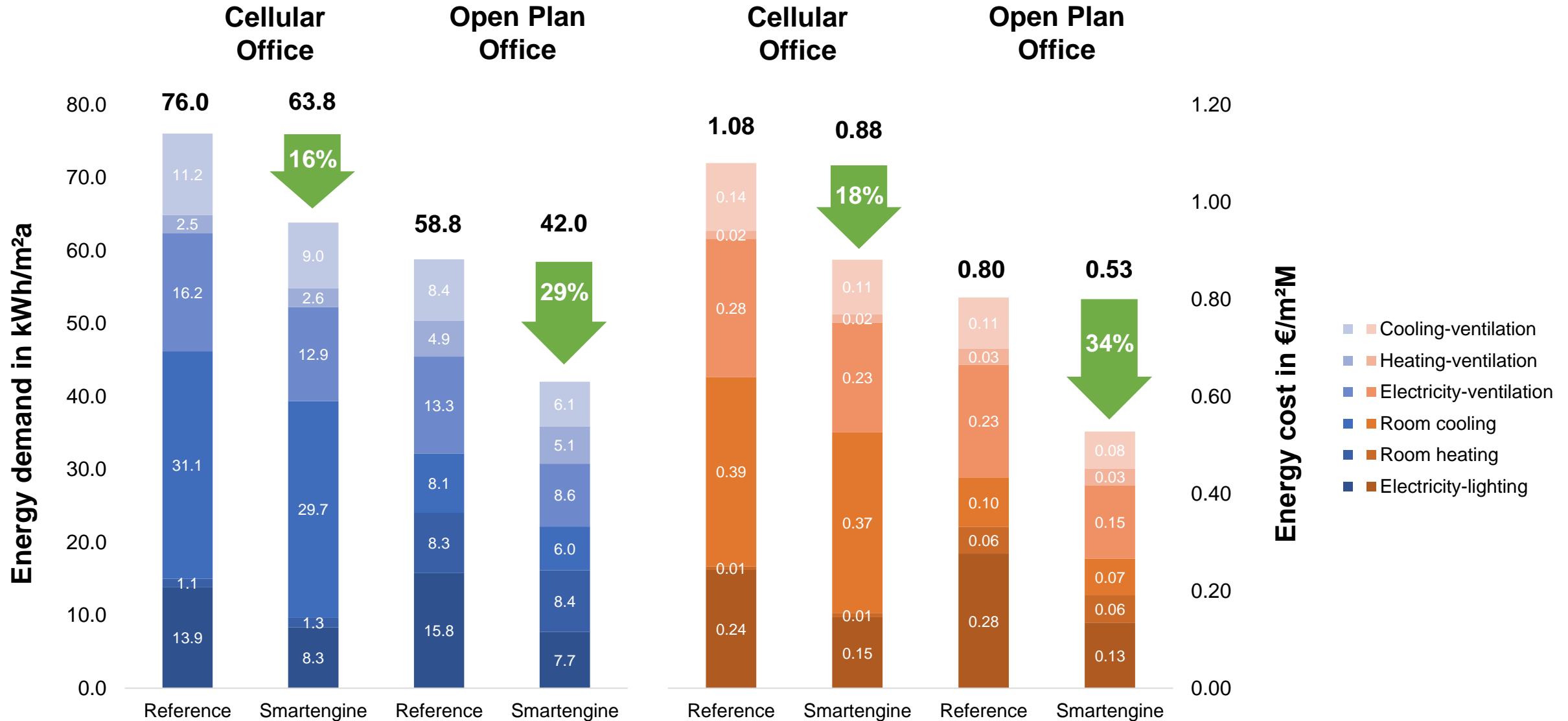
# Results of RWTH study: energy demand



# Results of RWTH study: energy costs



# Results of RWTH study: energy demand & costs



# Energy and cost savings between reference and smartengine-variant

## ■ Cellular office

Energy price		
Electricity price	€/kWh	0.21
Heating price	€/kWh	0.08
Cooling price	€/kWh	0.15

			Reference	Smartengine-Variant	Saving	Saving in percentage
Energy demand	Electricity-lighting	kWh/m <sup>2</sup> a	13.89	8.34	5.55	40%
	Room heating	kWh/m <sup>2</sup> a	1.14	1.32	-0.18	-16%
	Room cooling	kWh/m <sup>2</sup> a	31.13	29.71	1.42	5%
	Electricity-ventilation	kWh/m <sup>2</sup> a	16.25	12.90	3.35	21%
	Heating-ventilation	kWh/m <sup>2</sup> a	2.47	2.59	-0.12	-5%
	Cooling-ventilation	kWh/m <sup>2</sup> a	11.16	8.97	2.19	20%
Energy cost	Electricity-lighting	€/m <sup>2</sup> M	0.24	0.15	0.10	40%
	Room heating	€/m <sup>2</sup> M	0.01	0.01	0.00	-16%
	Room cooling	€/m <sup>2</sup> M	0.39	0.37	0.02	5%
	Electricity-ventilation	€/m <sup>2</sup> M	0.28	0.23	0.06	21%
	Heating-ventilation	€/m <sup>2</sup> M	0.02	0.02	0.00	-5%
	Cooling-ventilation	€/m <sup>2</sup> M	0.14	0.11	0.03	20%
	<b>Sum</b>	<b>€/m<sup>2</sup>M</b>	<b>1.08</b>	<b>0.88</b>	<b>0.20</b>	<b>18%</b>

# Energy and cost savings between reference and smartengine-variant

## ■ Open-plan office

Energy price		
Electricity price	€/kWh	0.21
Heating price	€/kWh	0.08
Cooling price	€/kWh	0.15

			Reference	Smartengine-Variant	Saving	Saving in percentage
Energy demand	Electricity-lighting	kWh/m <sup>2</sup> a	15.79	7.70	8.09	51%
	Room heating	kWh/m <sup>2</sup> a	8.26	8.45	-0.19	-2%
	Room cooling	kWh/m <sup>2</sup> a	8.11	5.99	2.11	26%
	Electricity-ventilation	kWh/m <sup>2</sup> a	13.29	8.64	4.65	35%
	Heating-ventilation	kWh/m <sup>2</sup> a	4.92	5.10	-0.18	-4%
	Cooling-ventilation	kWh/m <sup>2</sup> a	8.42	6.12	2.30	27%
Energy cost	Electricity-lighting	€/m <sup>2</sup> M	0.28	0.13	0.14	51%
	Room heating	€/m <sup>2</sup> M	0.06	0.06	0.00	-2%
	Room cooling	€/m <sup>2</sup> M	0.10	0.07	0.03	26%
	Electricity-ventilation	€/m <sup>2</sup> M	0.23	0.15	0.08	35%
	Heating-ventilation	€/m <sup>2</sup> M	0.03	0.03	0.00	-4%
	Cooling-ventilation	€/m <sup>2</sup> M	0.11	0.08	0.03	27%
	<b>Sum</b>	<b>€/m<sup>2</sup>M</b>	<b>0.80</b>	<b>0.53</b>	<b>0.28</b>	<b>34%</b>

# Possible reasons for the differences

## ■ General

- ≡ Synchronization of profiles of ventilation and people/machine/lighting for open-plan offices – start with a Monday
- ≡ Coupled dynamic calculation of room thermal behaviors affected by ventilation and internal gains
- ≡ ~~Control of room heater and cooler with air temperature (RWTH) instead of operative temperature (ROM)~~

Solved on 18.05.2020

## ■ Cooling-ventilation

- ≡ ~~AHU with thermal wheel and leakage (RWTH) and hence undesired heat recovery instead of heat recovery bypass (ROM) – extract air may warm up outdoor air in summer and thus increase cooling demand of AHU~~

Solved on 18.05.2020

## ■ Room cooling

- ≡ ~~The ROM reference simulations enable variable window blinds (shading), the RWTH simulations are without blinds. This leads to higher cooling loads, especially for the cellular office due to the high window to room volume ratio.~~

Solved on 18.05.2020, threshold of irradiation for sun shading is 150 W/m<sup>2</sup>

- ≡ **The model does not consider heat transfer between zones (both RWTH and ROM for the cellular office; ROM considers this for the open space office). In the current approach, each room is a individual zone. The cooling demand of south faced zones may be overrated.**
- ≡ Conflict between AHU and room cooler, e.g. AHU in heating mode and room cooler also active

## ■ Electricity-lighting

- ≡ Inclusion of energy consumption of smartengine infrastructure (open-plan office)



# Project wrap-up

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- Two office types were simulated with two different approaches
  - ≡ ROM: energy+
  - ≡ RWTH: Modelica
- Results
  - ≡ Very similar (with some deviations due to different approaches)
  - ≡ Smartengine saves 18-34% of operation costs (RWTH results)

