PATHFNDR project

CESAR-P

Empa-Urban Energy Systems Laboratory
Kristina Orehounig

CESAR - P

Combined Energy Simulation And Retrofitting (Python) is a software to evaluate **energy consumption and retrofitting strategies** for buildings and neighborhoods.

CESAR-P was developed by the Urban Energy Systems Lab at Empa and builds on the tool **CESAR** which was developed at the Chair of Building Physics at ETH Zurich.

Retrofit modelling – change in energy demand

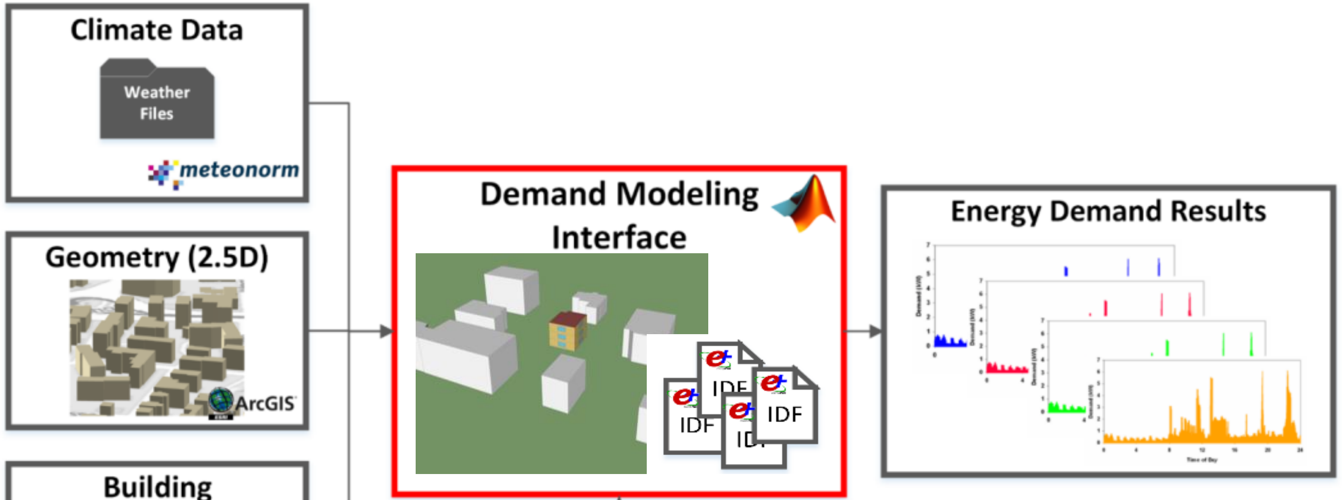
Business as usual

Retrofit modelling – change in energy demand

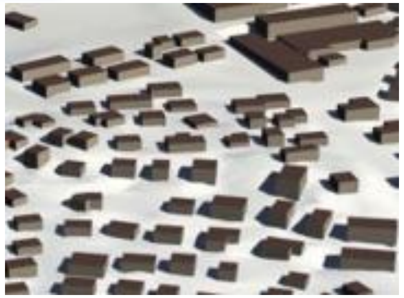
New Energy Policy

CESAR - P

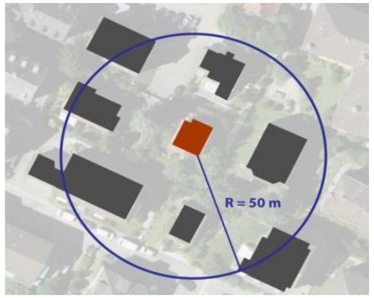
Combined Energy Simulation And Retrofitting (Python) is a software to evaluate **energy consumption and retrofitting strategies** for buildings and neighborhoods.



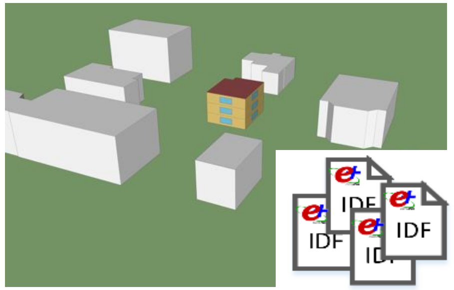
- Bottom-up building stock simulation tool to simulate **each building individually**
- Takes shading of **surrounding objects into account**



Pre-processed 3D buildings geodata -



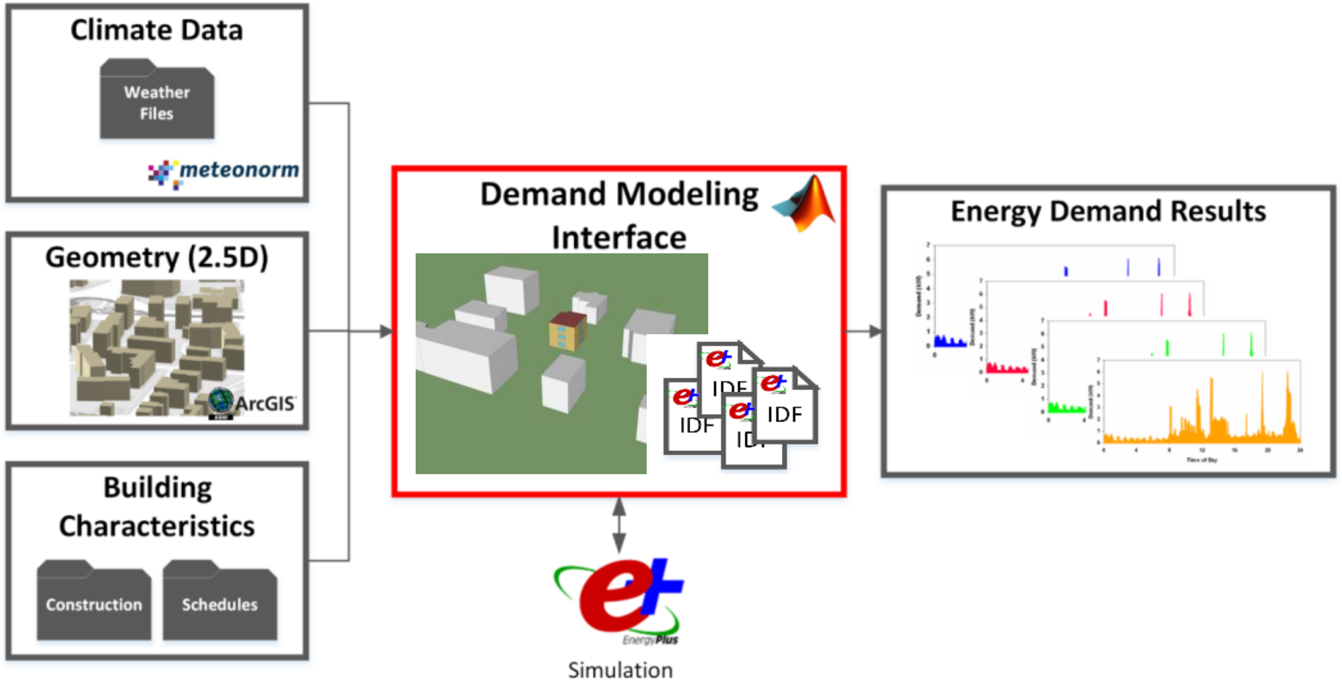
Neighboring buildings are considered as shading objects



Automated process – central building – idf files generated

CESAR - P

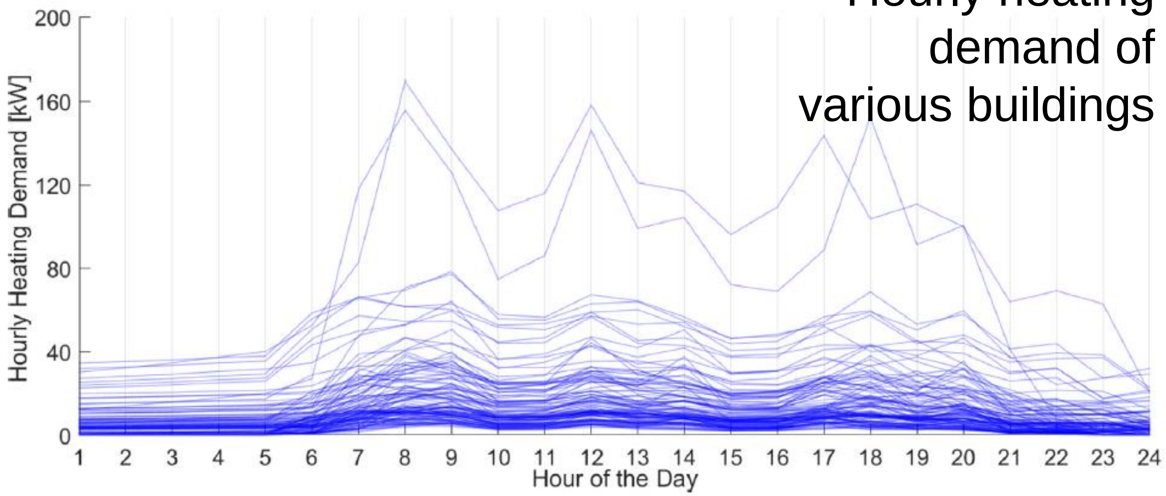
Combined Energy Simulation And Retrofitting (Python) is a software to evaluate **energy consumption and retrofitting strategies** for buildings and neighborhoods.



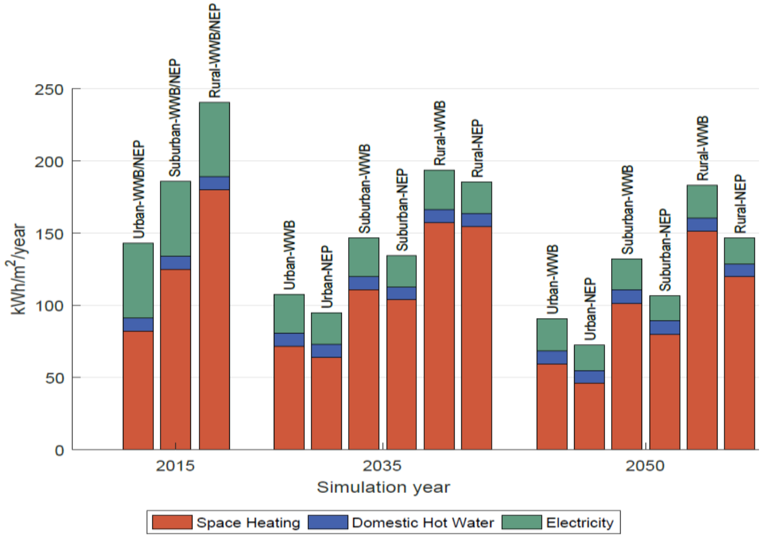
- Bottom-up building stock simulation tool to simulate **each building individually**
- Takes shading of **surrounding objects into account**
- Python based tool which uses the **building simulation tool EnergyPlus**
- Connected to **various databases** for building construction, costs, emissions, use profiles, geometries

Features

- Models **individual buildings**' indoor temperatures, **heating and cooling loads**, domestic hot water consumption, electricity consumption, comfort parameters
- Future retrofitting strategies can be simulated (e.g. insulating of walls, windows, roofs,…)
- Outputs operational costs and emissions, embodied emissions and investment costs of retrofitting solutions



Hourly heating demand of various buildings



Retrofitting strategies of districts

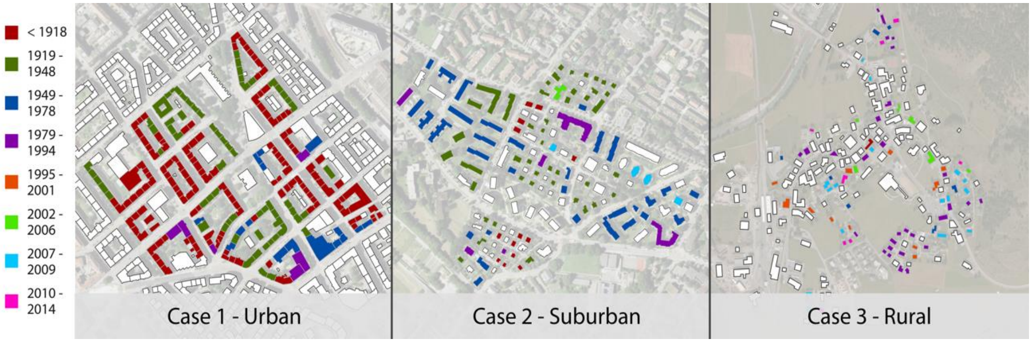
Spatial and temporal resolution

- Spatial coverage: Switzerland
- Spatial resolution: building level

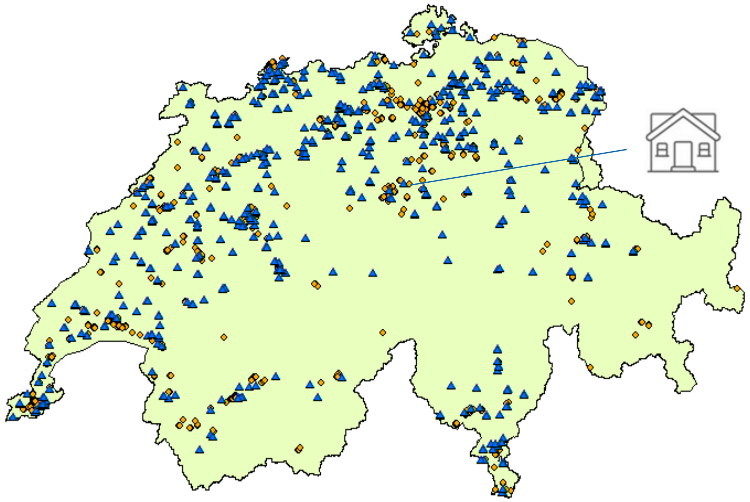
- Temporal coverage: dependent on weather file
- Temporal resolution: hourly (also 10min possible)

- Sector coverage: space heating, cooling, domestic hot water, electricity

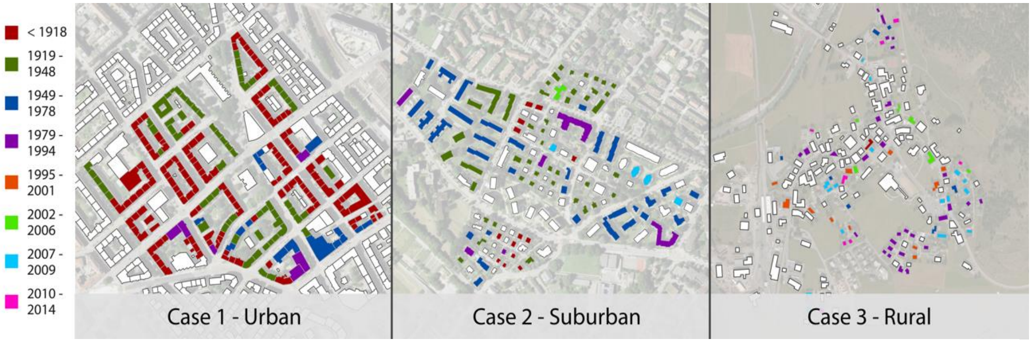
Neighborhoods

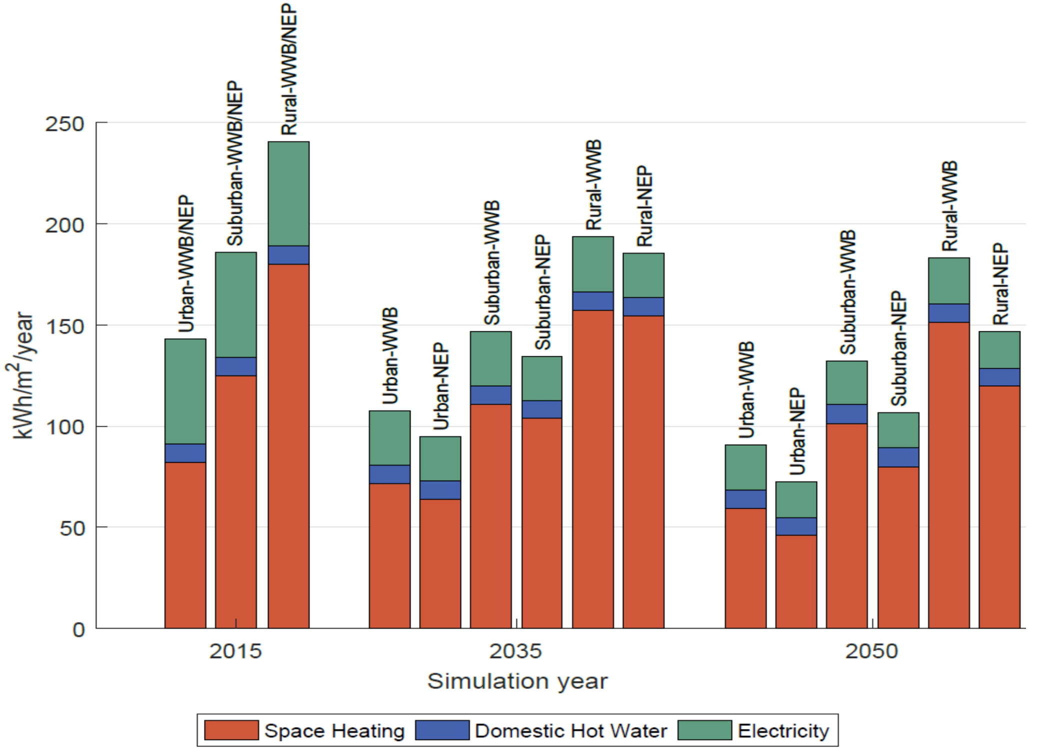


Typical buildings in Switzerland



Case study:
Urban – Suburban – Rural districts





Project objectives:

- Evaluate the current and future energy consumption of buildings

Key outcomes:

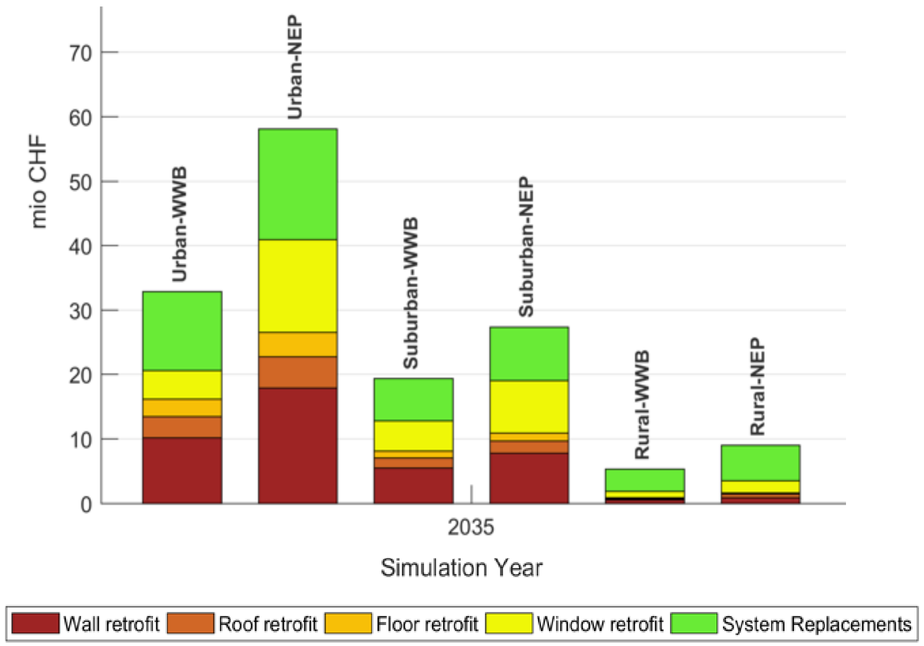
- Change in energy consumption under different transformation scenarios (Swiss Energy Strategy 2050)

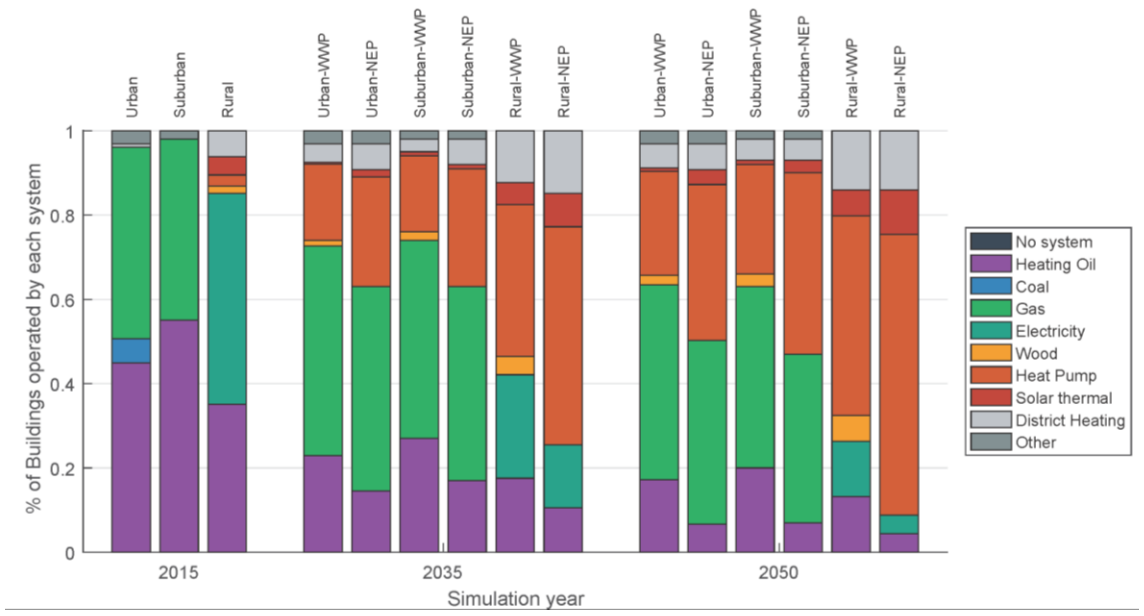
Wang, et al. (2018) 'CESAR: A bottom-up housing stock model for Switzerland to address sustainable energy transformation strategies' Energy and Buildings Vol 169, 9-26.

Case study:
Urban – Suburban – Rural districts

Key outcomes:

- District total **retrofitting investment costs** for different transformation scenarios (considering envelope retrofitting and system replacement)
- **Heating system shares** and transformations until 2050 for the three districts and the different transformation scenarios





PATHFNDR

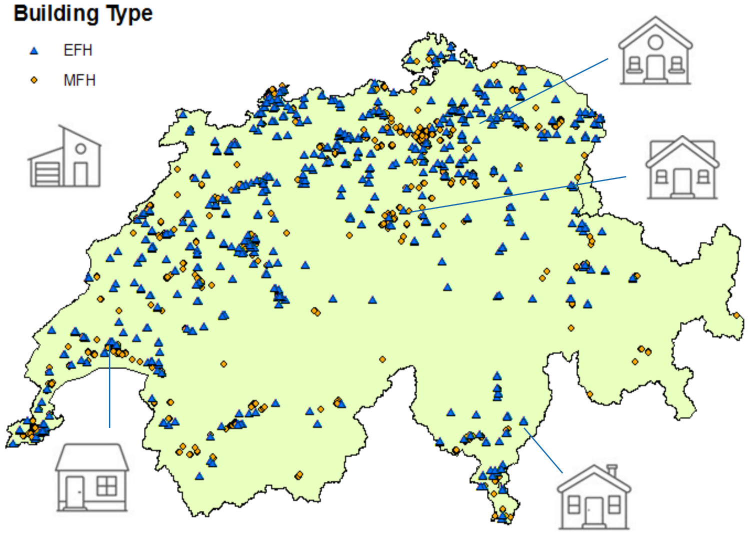
Wang, et al. (2018) 'CESAR: A bottom-up housing stock model for Switzerland to address sustainable energy transformation strategies' Energy and Buildings Vol 169, 9-26.

Case study:
Optimal retrofitting solutions for Swiss buildings

NFP70: Energiewende und technische Regulation EnTeR

Project objectives:

- Assess optimal retrofitting solutions for typical buildings in Switzerland
- Evaluate costs, operational and embodied CO2 emissions



500 single and multi-family buildings which represent 1.8 Mio buildings

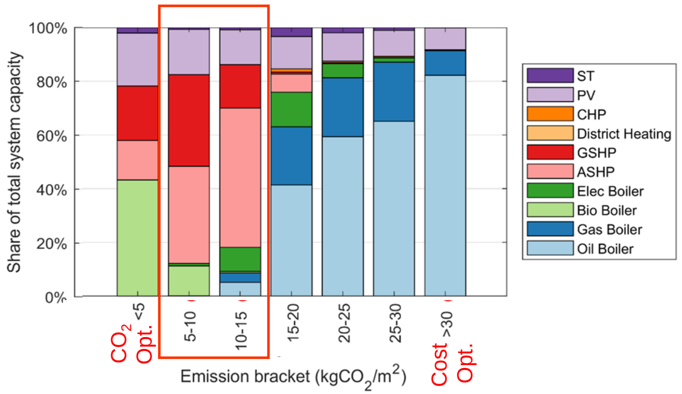
Murray et al. (2020) ‘Optimal transformation strategies for buildings, neighbourhoods and districts to reach CO2 emission reduction targets’ Energy and Buildings Vol 207.

Case study:
Optimal retrofitting solutions for Swiss buildings

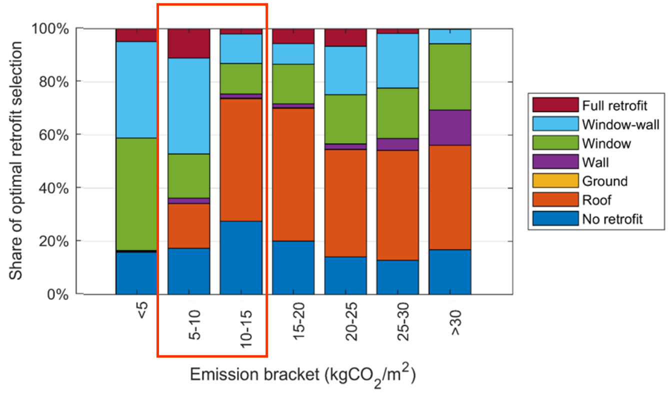
Key outcomes:

- CESAR is used for demand simulation together with an energy hub optimization approach
- 10 most promising retrofitting solutions to reach goals of the SIA-Effizienzpfad Energie

Typical solutions: building systems

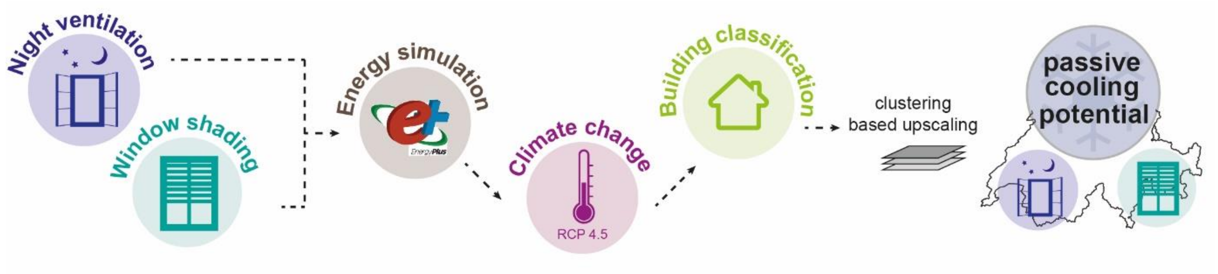


Typical solutions: envelope retrofitting

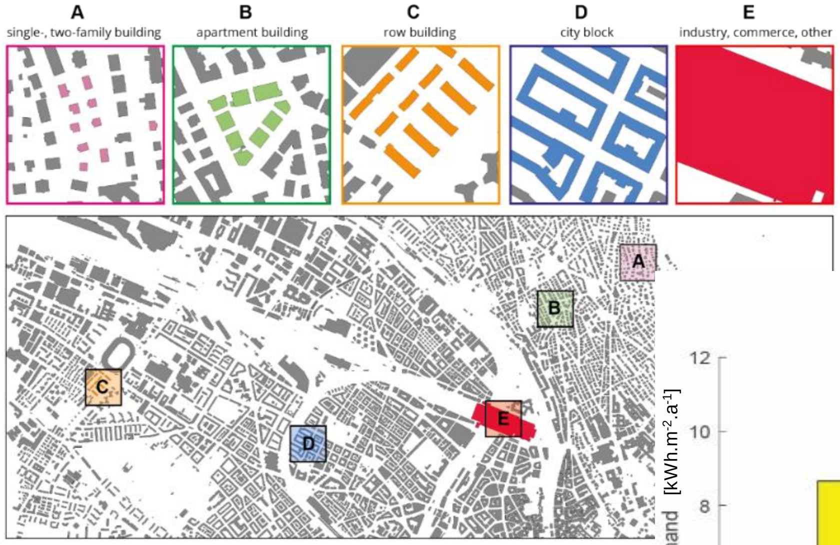


Murray et al. (2020) 'Optimal transformation strategies for buildings, neighbourhoods and districts to reach CO2 emission reduction targets' Energy and Buildings Vol 207.

Case study:
Passive cooling potential in 2050



SCCER FEEB&D - Urban Planning for Smart & Resilient Cities/Communities

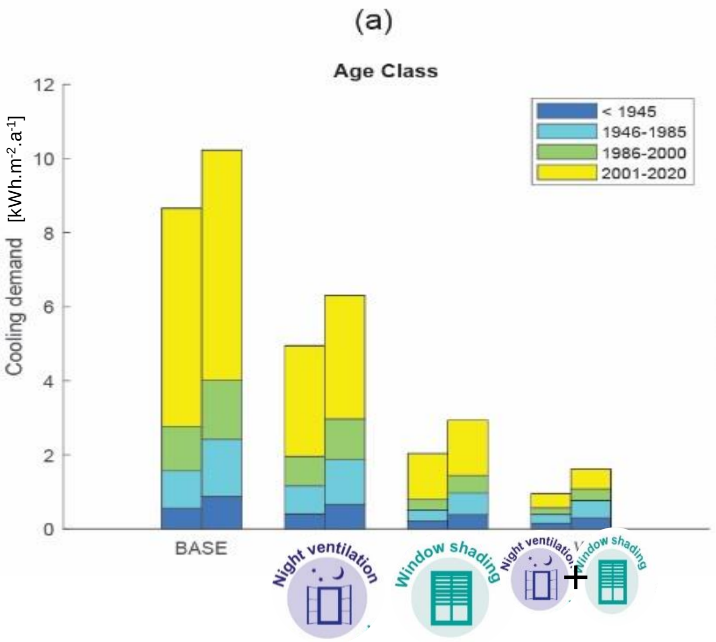


Project objective:

- Evaluate passive cooling potential for Swiss buildings in 2050

Key outcomes:

- Cooling demand under different climate change scenarios
- How effective is night ventilation and window shading as passive cooling measures



Silva et al. 2021 Opportunities for passive cooling to mitigate the impact of climate change in Switzerland, Building and Environment, submitted.

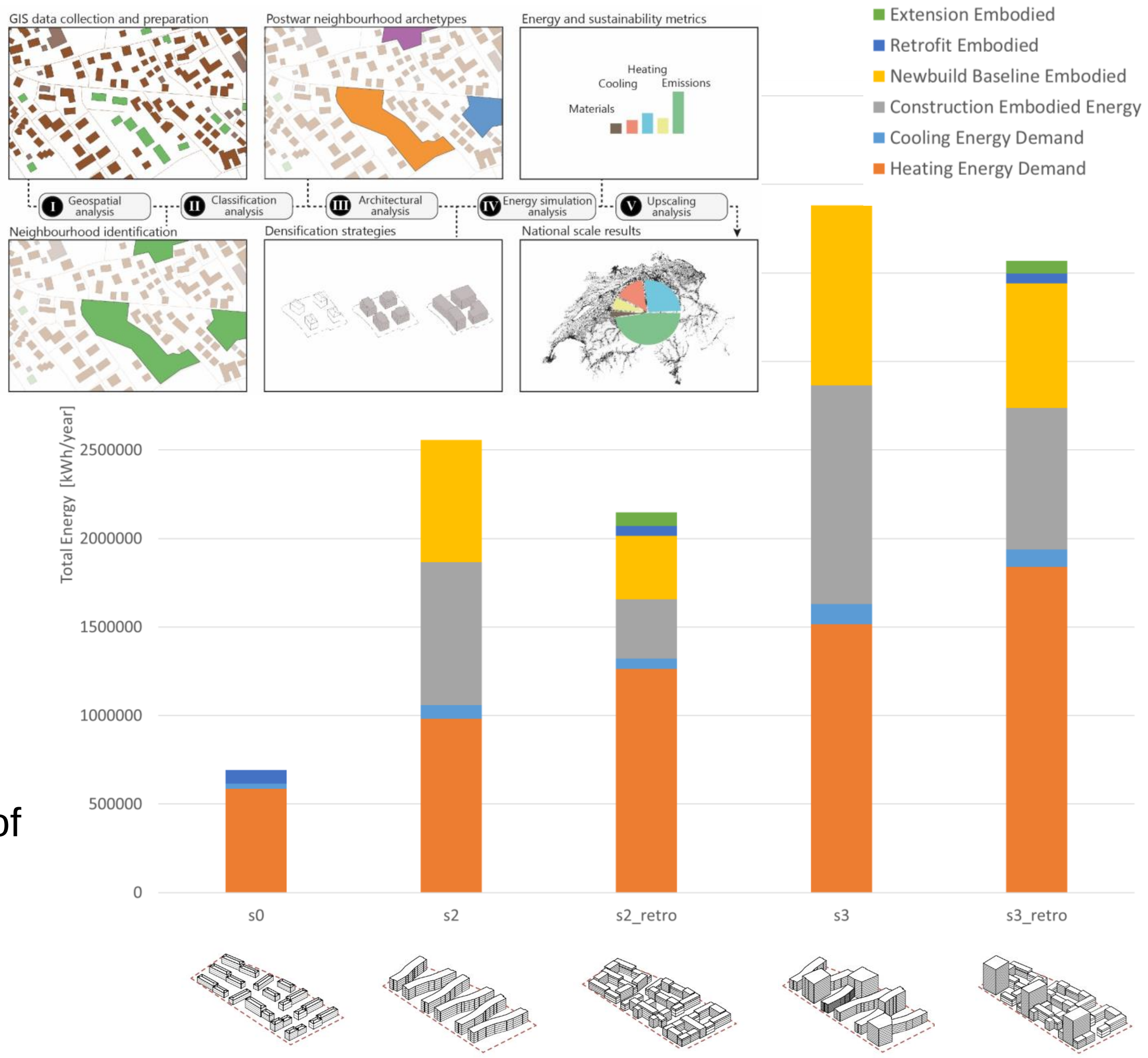
Case study:
Urban densification and its impact on energy use

SFOE project StaVerdi

- Extended CESAR-P to include the embodied emissions of new builds

Key outcomes:

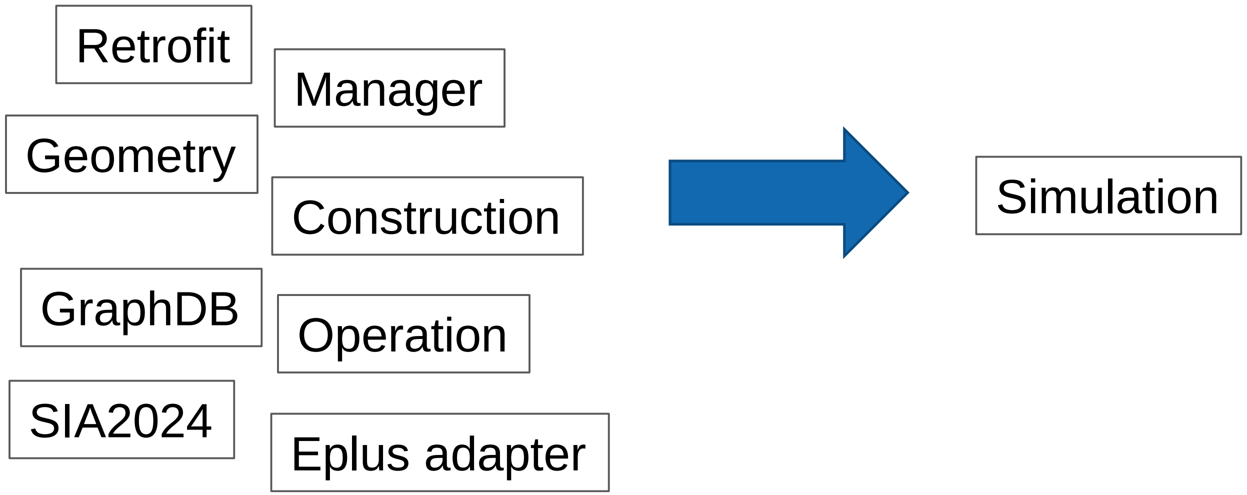
- A timber strategy for the new builds had 50% less emissions than the concrete
- Densification strategies involving a mix of new and old should address both the performance of retrofitted buildings and the embodied emissions of new builds



Eggimann et al. (2021) ‘Geospatial assessment of sustainable urban densification potentials’ Sustainable Cities and Society.

CESAR-P Architecture

- CESAR-P has a modular structure that is managed by individual .yml config files
- These are combined by CESAR-P
- Elements of the configs can be redefined by the user



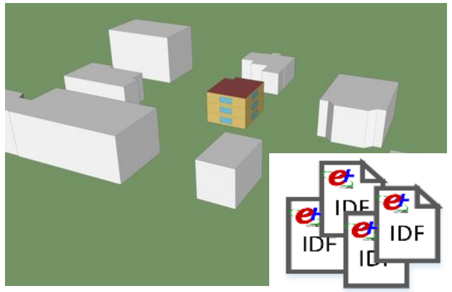

```yaml
GEOMETRY:
    NEIGHBOURHOOD:
        RADIUS: 50 # meter

    MAIN_BLDG_SHAPE:
        MINIMAL_STORY_HEIGHT: 3.0  # meter

SIA2024:
    # The package-default config stores SIA Profiles within its package, which is not that good. Thus, s
    # where you want your SIA Profiles stored here.
    # In case you use the ProjectManager. If you want to have different profile sets for different scena
    # use scenario specific config to set different pathes per scenario, otherwise porfiles of first cre
    PARAMSETS_VARIABLE_SAVE_FOLDER: "./sia_params_gen/variable/"
    PARAMSETS_NOMINAL_SAVE_FOLDER: "./sia_params_gen/nominal/"

# You can add here custom configuration for the cesar packages. This will overwrite package default con
# For configuration options see default_config.yml in the packages/folders, e.g. geometry or constructi

EPLUS_ADAPTER:
    EPLUS_VERSION: "9.3.0"

GRAPHDB_ACCESS:
  # class specified here must be compatible with cesarp.manager.BldgModelFactory.ArchetypicalConstructi
  ARCHETYPE_CONSTRUCTION_FACTORY_CLASS: "BuildingSpecificArchetypConstructionFactory.BuildingSpecificArc
  FIXED_INFILTRATION_PROFILE_VALUE: 1
  LOCAL:
    ACTIVE: False
  REMOTE:
    ACTIVE: True
    SPARQL_ENDPOINT: "http://emp-graphdb01.empa.emp-eaw.ch:7200/repositories/ues_building_archetypes"

OPERATION:
    NIGHT_VENTILATION:
        ACTIVE: TRUE
```


Example user defined config file

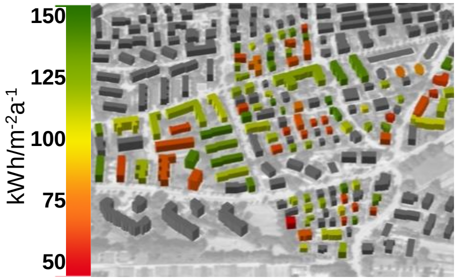
Process

Modelling

1. Building Model Generation
2. Retrofitting Selection
3. EnergyPlus Simulations
4. Results processing



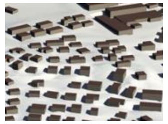
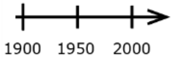
Automated building model generation



Simulated results for the neighborhood

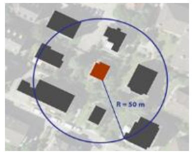
Process

Input

- Building footprint and height

- Year of construction


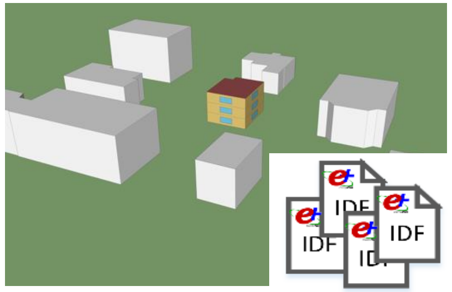
- Building type (residential, office,…)

- Hourly weather data (epw)

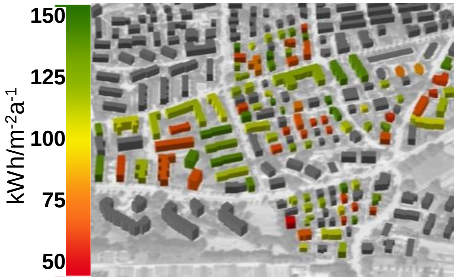
- For Shading: footprints and height of neighboring buildings


Modelling

1. Building Model Generation
2. Retrofitting Selection
3. EnergyPlus Simulations
4. Results processing



Automated building model generation

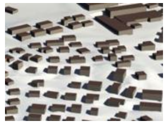


Simulated results for the neighborhood

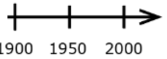
Process

Input

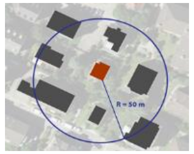
- Building footprint and height



- Year of construction

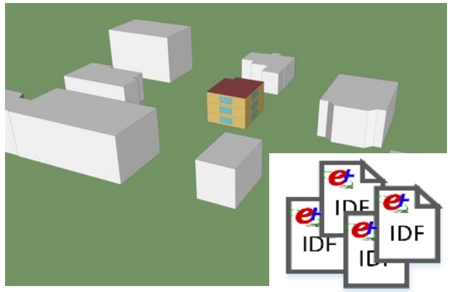


- Building type (residential, office,…)
- Hourly weather data (epw)
- For Shading: footprints and height of neighboring buildings

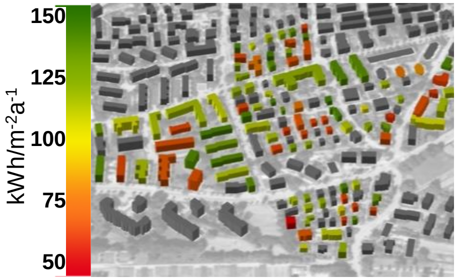


Modelling

1. Building Model Generation
2. Retrofitting Selection
3. EnergyPlus Simulations
4. Results processing



Automated building model generation

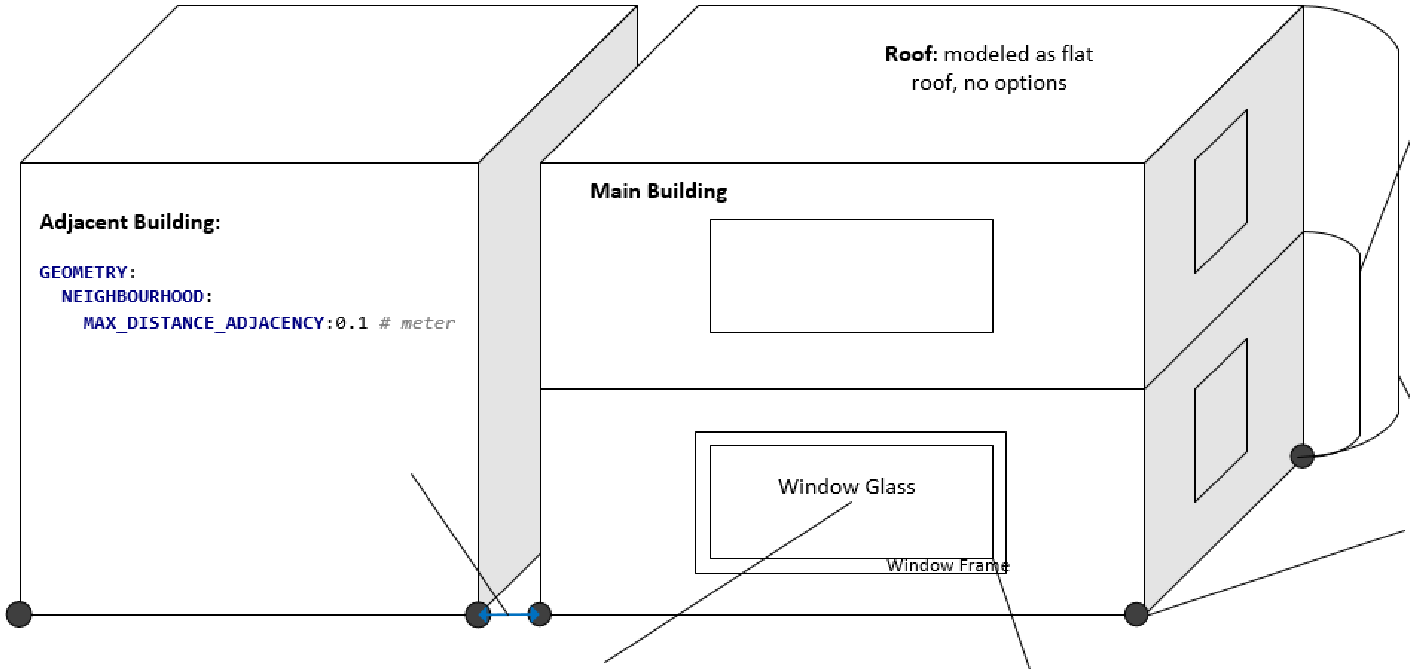


Simulated results for the neighborhood

Output

- Annual demands
  - Space heating
  - Space cooling
  - Domestic hot water
  - Electricity
- *Hourly results can be queried on demand*
- Operational costs and emissions
- Retrofit measures
- Retrofitting costs and embodied emissions

Geometry Creation: inputs and configuration parameters



Story-Height/Number of floors:
Actual story height is defined as following, ensuring building height and volume to be as defined for each building individually:

Building height is read together with building footprint vetices.

```
GEOMETRY:
  MAIN_BLDG_SHAPE:
    MINIMAL_STORY_HEIGHT: 2.4
```

Footprint-Vertices + Building Height: either defined in a csv file or as a shp file – CESAR-P selects correct parser according to file extension.
Input file contains footprints + height for **all buildings** on the site.

```
MANAGER:
  SITE_VERTICES_FILE:
    PATH: YOUR_PROJECT_PATH\SiteVertices.csv/.shp
    LABELS:
      gis_fid: TARGET_FID
      height: HEIGHT
      x: POINT_X
      y: POINT_Y
```

Window Area / Glazing ratio:
One window is modeled in the middle of each wall, with defined HEIGHT and width calculated to match requested glazing ratio.

```
GEOMETRY:
  MAIN_BLDG_SHAPE:
    WINDOW:
      HEIGHT: 1.5 # m
```

Window Frame: applied to all windows

```
GEOMETRY:
  MAIN_BLDG_SHAPE:
      WINDOW_FRAME:
        WIDTH: 0.04 # m
```

Construction and Operation Properties

Building Age and Building Type:
Defined per Building.
Building Type is according to SIA2024, for available building types see cesarp.SIA2024.ressources.building_types.yml

```
MANAGER:
  BLDG_AGE_FILE:
      PATH: "TBD_BLDG_AGE_FILE.csv"
      SEPARATOR: ","
      LABELS:
          gis_fid: "ORIG_FID"
          year_of_construction: "BuildingAge"
  BLDG_TYPE_PER_BLDG_FILE:
    PATH: "TBD_BLDG_TYPE_PER_BLDG_FILE.csv"
    SEPARATOR: ","
    LABELS:
      gis_fid: "ORIG_FID"
      sia_bldg_type: "SIA2024BuildingType"
```

Window Shading
Three different shading devices/materials selected **depending on building age**.
To activate set (Default: active):

```
OPERATION:
  WINDOW_SHADING_CONTROL:
    ACTIVE: True
    ...
```

Installation Characteristics:
fixed for all buildings of the site, heat losses for lighting, activity, dhw and appliances. Parameters specified in configuration of cesarp.construction

```
CONSTRUCTION:
    FIXED_INSTALLATION_CHARACTERISTICS:
        ...
```

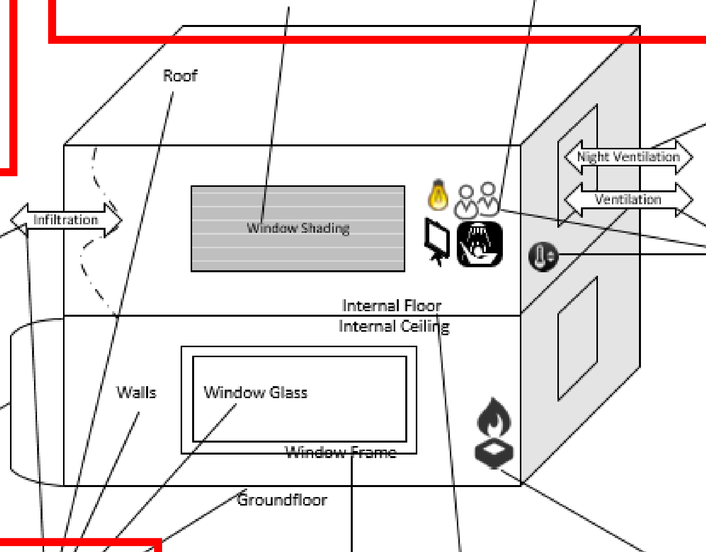
Night Ventilation
Fixed for all buildings on the site:
To activate set (Default: inactive)

```
OPERATION:
    NIGHT_VENTILATION:
        ACTIVE: True
```

Infiltration Rate
You can use Infiltration rate defined by **SIA2024** based on the Building Type or from **constructional archetype** based on Building Age as described below.

```
MANAGER:
  INFILTRATION_RATE_SOURCE: "SIA2024" | "Archetype"
```

Thermal Zone:
Each floor is modeld as one Zone in EnergyPlus input file.
All zones have identical properties. No configuration options.



Operation / Occupant behaviour:

Defined are:
- Floor area per person, occupancy schedule
- Lighting, appliances, DHW, ventilation, people activity levels and schedules
- Thermostat setpoint schedule for heating and cooling

Those parameters and schedules/profiles can either be generated according to **SIA2024 depending on the Building Type** or they can be set **fixed** for all buildings of the site.

```
MANAGER:
    BUILDING_OPERATION_FACTORY_CLASS:
"cesarp.SIA2024.SIA2024Facade.SIA2024Facade" |
"cesarp.operation.fixed.FixedBuildingOperationFactory.FixedBuildingOperationFactory" | CUSTOM_CLASS
    SIA2024_VARIABILITY: False
```

Building age dependent constructional Archetype

- **Window Glass Construction**
- **Wall Construction**
- **Groundfloor Construction**
- **Roof Construction**

- **Infiltration Rate** (can be defined over SIA2024 as well, see above)
- **Galzing Ratio** (can also be set per Bldg, see on Geometry diagram)

```
MANAGER:
 RANDOM_CONSTRUCTIONS: False | True
```

As a Data Source for constructional informationIDF Files or a GraphDB can be used.

```
CONSTRUCTION:
    CONSTRUCTION_DB: "GRAPH_DB" | "IDF_FILES_DB"
```

When using the GRAPH_DB, you can define your own Archetype Factory in order to implement a custom Archetype assignment to your buildings.

Window Frame Construction:
fixed for all buildings of the site, parameters specified in configuration of cesarp.construction

```
CONSTRUCTION:
    FIXED_WINDOW_FRAME_CONSTRUCTION_PARAMETERS:
        ...
```

Internal Floor and Ceiling Construction:
fixed for all buildings of the site, parameters specified in configuration of cesarp.construction

```
CONSTRUCTION:
 FIXED_INTERNAL_FLOOR_CONSTRUCTION_PARAMETERS:
    ...
 FIXED_INTERNAL_CEILING_CONSTRUCTION_PARAMETERS:
    ...
```

Energy Source DHW and Heating:
Used for calculation of operational costs&emission.
Efficiency of heating is depending on the simulation year and chosen energy strategy.

```
MANAGER:
  DO_CALC_OP_EMISSIONS_AND_COSTS: True
  BLDG_INSTALLATION_FILE:
      PATH: "TBD_BLDG_INSTALLATION_FILE.csv"
      SEPARATOR: ","
      LABELS:
          gis_fid: "ORIG_FID"
          dhw_energy_carrier: "ECarrierDHW"
          heating_energy_carrier: "ECarrierHeating"

SITE:
  SIMULATION_YEAR: 2015
ENERGY_STRATEGY:
  ENERGY_STRATEGY_SELECTION: WWB | NEP
```

Building Container Class

- **Building Container** is a class that **stores the building model**, the **results and the assumptions**
- These containers are stored as json files alongside the EnergyPlus outputs
- Python functions inside CESAR-P can read and analyze the contents of the BuildingContainers for post processing and resimulation

bldg_container_fid_0.json
bldg_container_fid_1.json
bldg_container_fid_2.json
bldg_container_fid_3.json
bldg_container_fid_4.json
bldg_container_fid_5.json
bldg_container_fid_6.json
bldg_container_fid_7.json
bldg_container_fid_8.json
bldg_container_fid_9.json
bldg_container_fid_10.json

Building containers are created for individual buildings


```
"tot_heating_demand": {
    "py/reduce": [
        {
            "py/function": "pint._unpickle"
        },
        {
            "py/tuple": [
                {
                    "py/type": "pint.quantity.Quantity"
                },
                48259.8491766953,
                {
                    "_d": {
                        "__dict__": {},
                        "kilowatt_hour": 1.0,
                        "py/object": "pint.util.udict",
                        "year": -1.0
                    },
                    "_hash": -6131551856237606936,
                    "py/object": "pint.util.UnitsContainer"
                }
            ]
        }
    ]
},
```


Total heating demand stored inside the building container

Retrofitting

- CESAR-P treats each of the building elements separately during the retrofit

- It is possible to investigate strategies involving any combination of:
  - Roof
  - Walls
  - Window
  - Ground Floor

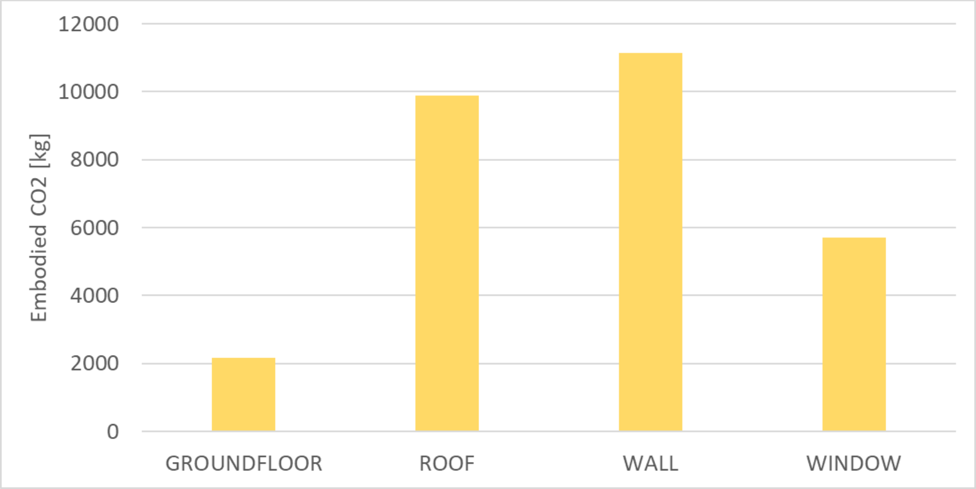
- CESAR-P outputs a ‘retrofit log’ containing the embodied emissions for each element investigated in the specified case.

Example script to create a retrofit study:

```
self.retrofit_manager = SimpleRetrofitManager(ureg=cesarp.common.init_unit_registry(),
                                              base_config=self.config_dict,
                                              base_scenario_name="orig",
                                              base_project_path=self.output_path,
                                              year_of_retrofit=2020,
                                              fids_to_use=None)
```

Creating a ‘full retrofit’ case, comprised of roof, wall, window and ground floor:

```
self.retrofit_manager.add_retrofit_case("full_retrofit", [BuildingElement.ROOF,
                                                          BuildingElement.WALL,
                                                          BuildingElement.WINDOW,
                                                          BuildingElement.GROUNDFLOOR])
```

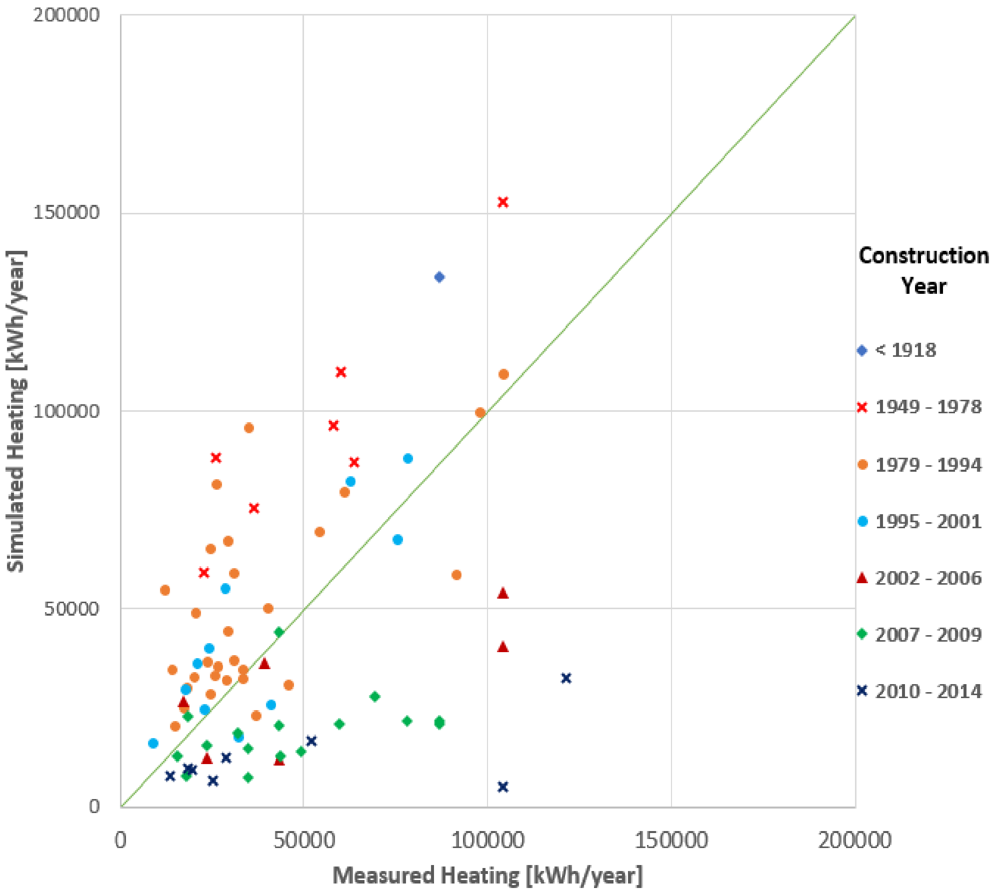


Average embodied emissions across a neighbourhood for each retrofitted building element

Validation / calibration

- Compared outputs of CESAR to annual heating energy consumption of buildings in Zernez
- Overall accuracy quite good
- Individual buildings show in some cases very high differences between measured and simulated

- Further calibration activities are currently ongoing



	Measured	Simulated	Deviation [%]
Total Heating demand [GWh/Year]	3.366	3.331	-1.05

Wang, et al. (2018) 'CESAR: A bottom-up housing stock model for Switzerland to address sustainable energy transformation strategies' Energy and Buildings Vol 169, 9-26.

Limitations

- Databases are currently only for Switzerland available
- Geometry input is in 2.5D, roofs are assumed to be flat and each floor is modelled as one thermal zone
  -> more advanced geometry input is under development.
- No user-interface is currently available

Linkage to other tools of the PATHFNDR project

- CESAR-P & Ehub tool:

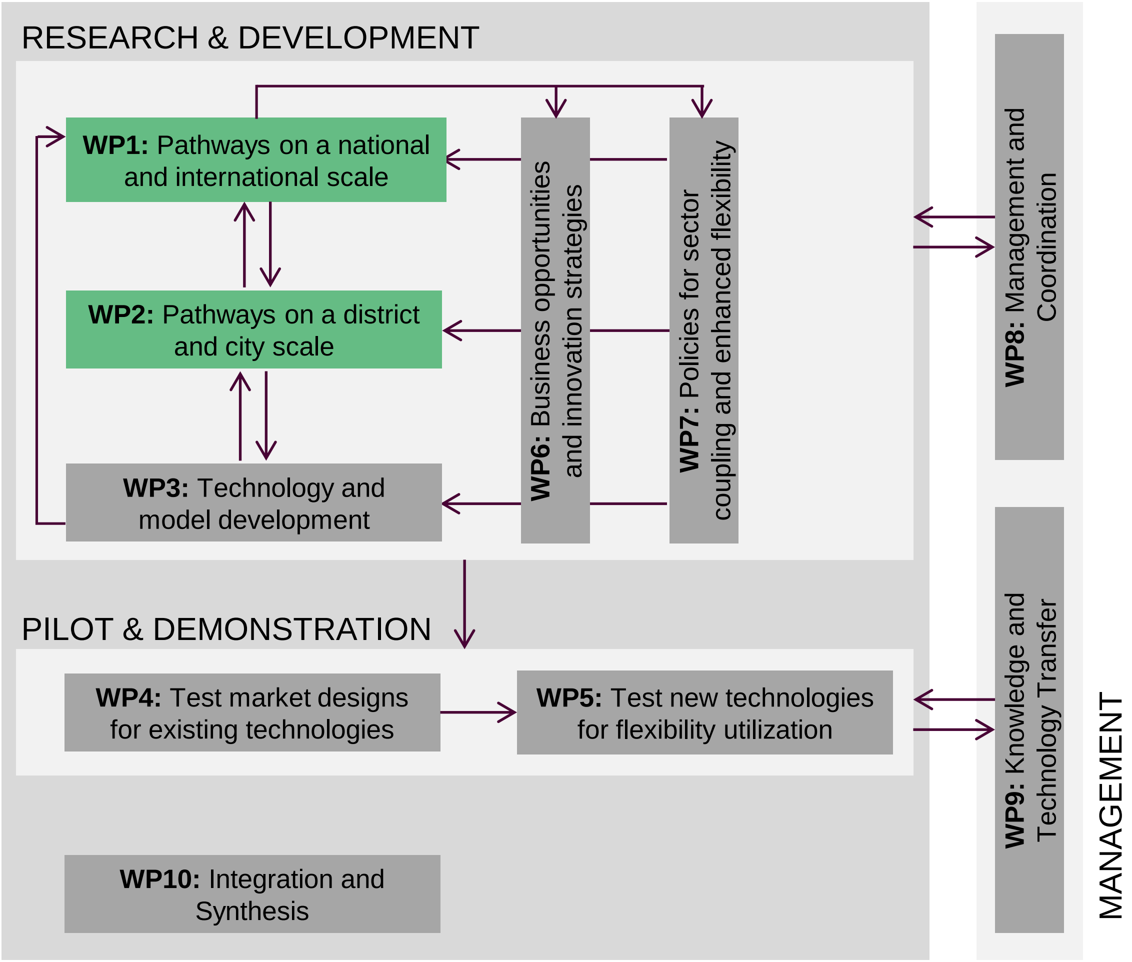
  Output of CESAR-P (energy demand of districts) is used in an Energy hub optimization as input

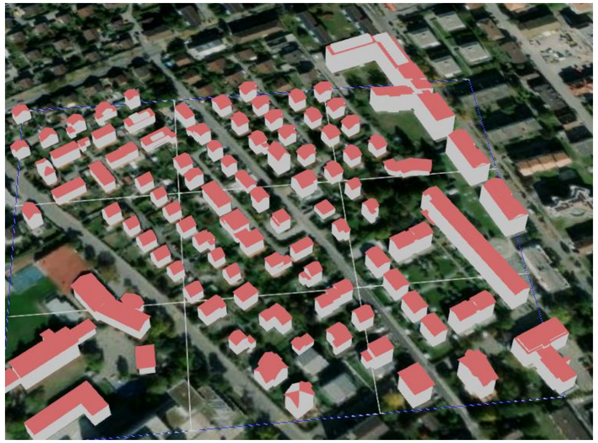
Potential links:

- CESAR-P & Nexus-E (energy demand inputs)
- CESAR-P & Calliope (energy demand inputs)
- CESAR-P & ReMap (energy demand inputs)

Future development under the PATHFNDR project

- WP1: extend the scope to other European countries (e.g. archetype buildings) and derive demand profiles for other countries
- WP2: integrate demand flexibilities in CESAR-P
- Direct import of CityGML geometries containing roof geometries and building parts





Building surfaces of the SwissTopo CityGML model viewed in Cesium

Users

Current users:

- Researchers in the field of energy system modelling (city, regional or national level)

Potential users:

- Cities and communities
- Consultants for energy system planning
- …

License

- AGPLv3 open source license.
- Further information: https://www.empa.ch/web/s313/software-tools
- Source code: https://github.com/hues-platform/cesar-p-core
- Documentation: https://cesar-p-core.readthedocs.io/en/latest/
- Download: https://pypi.org/project/cesar-p/

Contributors

CESAR-P:

- Leonie Fierz
- James Allan
- Ricardo Silva
- Aaron Bojarski
- Sven Eggimann
- Natasa Vulic
- Portia Murray
- Kristina Orehounig

CESAR:

- Danhong Wang
- Jonas Landolt
- Georgios Mavromatidis
- Kristina Orehounig

Kristina Orehounig
kristina.orehounig@empa.ch
Empa, Urban Energy Systems Laboratory

PATHFNDR: https://sweet-pathfndr.ch/models/
CESAR-P: https://www.empa.ch/web/s313/software-tools