A SCALABLE APPROACH TO LOAD PROFILE DETERMINATION ON A CITY DISTRICT LEVEL, APPLICABLE IN EARLY PLANNING STAGES

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ABSTRACT

In the preliminary design process of large buildings or entire city districts, detailed information relevant for energy planning often is scarce. This necessitates coarse simulation models, accordingly. Common approaches simulate city districts either with multi-zone or single-zone buildings. The former requires high modeling efforts and details that might be unobtainable. The latter demands multiple simulations to adequately represent mixed uses. The presented approach finds its way between these, by pre-simulating representative type cells (based on SIA-2024 [1]) and scaling the results to the buildings or city districs in question. We provide a library with clear and simple input, output and extendable database via XLSX-files.

INTRODUCTION

During the design process of a larger building or an entire quarter or city district, consideration of its thermal energy supply should start at an early stage. Besides the maximum loads, temporally resolved annual load profiles are necessary as an input to energy system design – especially with the use of renewable energies (e.g. geothermal energy, solar energy, ...). There are several ways to determine these load profiles in advance: One of the simplest is to represent each building as a single-zone model using the monthly balance method. One of the most complex is to simulate each building as a fully coupled multi-zone model in a transient manner.

Here, an intermediate approach is presented: Each building considered is divided into its different usage zones (living, office, etc.), each usage zone is simulated with a simple transient single-zone model, and finally the thermal load results of all zones are summed up. Therefore hourly resolution can easily be achieved. A major challenge before any simulation is the parameterization of the model. Often, especially in the early design phase, the building and usage parameters are not yet known or are still to be varied. The approach described here uses the space utilization data according to SIA-2024. Usually, a large number of parameters are required for building simulation. SIA-2024 specifies a total of 124 values for each typical zone. These include, for example, the physical properties of the building, information on internal loads, and ventilation technology. A distinction is made between different building standards, namely existing (old), current standard, and (optimal) target value. The approach described here was programmed as a library in Python and named SimSIA in reference to SIA-2024.

MODELING APPROACH

The approach described here uses the definitions, assumptions, and parameter sets and values according to SIA-2024. These contain 45 different type-rooms and corresponding space utilization profiles. Together with other, analogously structured data sets they build the database, from which the input data is read. Transient heating and cooling load profiles for each type-room are generated with a simple a RC single-zone model (Fig. 1). Here T_e is the outdoor temperature, and T_i the room temperature. Only the heat transfer via external walls and windows is considered, whereas all interior walls (which might be adjacent to other zones) are assumed adiabatic, i.e. inter-zonal heat transfer is disregarded. This allows setting up each single-zone model in a simple manner without the necessity to define exact spatial relations between different zones. $R_{AW,a}, R_{AW,i}, R_{IW}$ represent the contact resistances of the walls (including windows), while C_{AW} and C_{IW} represent their thermal capacities. With $\dot{Q}_{conv}$ powers are described which act directly on the room air node (convectively), with $\dot{Q}_{rad}$ those which act radiatively on the wall inner surfaces of the room. The heating and

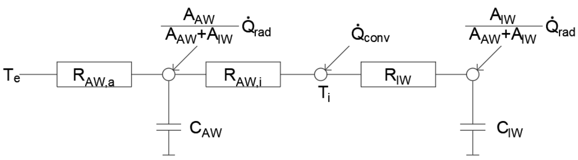

Figure 1. model's equivalent circuit diagram

cooling of the room are ideally assumed to be purely convective (c), the solar gains purely radiative ($1-c$).

Only the internal gains due to people, equipment and lighting are both, proportionally radiative and proportionally convective, as the following power balances show:

$$\dot{Q}_{conv} = \dot{Q}_{heat} + \dot{Q}_{cool} + c \cdot \dot{Q}_{int} \quad (1)$$
$$\dot{Q}_{rad} = \dot{Q}_{sol} + (1 - c) \cdot \dot{Q}_{int} \quad (2)$$

The parameterized models of all type-rooms are simulated in arbitrary temporal resolution. Resulting zone air temperatures, as well as specific powers, such as heating power, internal loads, and thermal losses, are obtained in relation to the floor area. From these results, buildings or entire quarters can be constructed as described below. To validate the described model approach, first three type-rooms (N1.01 Wohnen MFH, N1.02 Wohnen EFH, and N12.3 Treppenhaus)(Living Apt.House, Living SFH, and staircase) were simulated in four static test cases each (transmission only, +ventilation, +internal loads, +solar gains). The same rooms were then modeled in TRNSYS and simulated as well. Then a simple multi-zone building was modeled in SimSIA and TRNSYS. Their results were compared to discuss the differences, advantages and disadvantages of either software. This is described in the Analysis chapter.

Statistical smoothing

A feature of SimSIA is the ability of smoothing the generated time series. This redistributes peak loads to adjacent periods and can be used to represent the influences of a larger thermal storage mass, such as a buffer storage, or time shifts in occupancy profiles within one zone. Methodologically, this is achieved by blurring with a Gaussian normal distribution. The density function is used to determine the probabilities of positive and negative shifts in time. These serve as weights for the calculation of a centered, weighted, moving average over the time series. For the calculation of these weights, the following equation is used:

$$x_{smooth} = \frac{1}{\sqrt{2\pi} \cdot \sigma} \cdot e^{-\frac{x^2}{2 \cdot \sigma^2}} \quad (3)$$

where σ is the standard deviation, and x is an array of indices centered around zero. The resulting x_{smooth} is a kernel (array of weights) used in the subsequent convolution. The convolution applies the kernel to the data array, replacing each value with a weighted mean value and thus smoothing the data. The user can control the distribution with the parameter σ (standard deviation). The larger σ, the more the peaks are smoothed and distributed over the time periods around the value to be smoothed. Until now there is no link between a storage concept and the parameter σ.

IMPLEMENTATION

The presented approach is implemented as an executable library in Python.

Directories structure

This library consists of a single Python file called *"simsia.py"*. The database, in which the type-rooms are described, is an Excel file called *"DB_Raumdaten_Nutzungsprofile_SIA2024.xlsx"*.

The intermediate simulation results of type-rooms are stored in the directory *"4_Simulationsergebnisse"*, while *"5_Anwendung_auf_Gebaeude"* will contain folders with the final results after scaling to buildings. It is the default search path for buildings, too. The folder *"2_Wetterdaten"* contains the weather data necessary for the simulation.

Operation and file formats

The library defines functions that can be used to implement the presented approach in another software. The program itself can be executed via the command line. When used from the command line (see code 1), the `-b` and `-w` flags declare the building definition and weather file to be used. Both can be repeated to run multiple simulations in sequence. In this case, buildings and weather data sets are simulated in pairs for each simulation. If one of the flags has length one or the `-x` option is used, each building is simulated combined with each weather file. If either no building definition or no weather data set is provided, a simple file dialog on the command line requests the relevant file. It starts searching in the default search paths.

Code 1. Calling SimSIA on the command line
(Paths with spaces must be escaped or enclosed by quotes)

```
python simsia.py -b building.xlsx -w
    weathera.txt weatherb.txt -x
```

A *.xlsx file is expected as a building definition. Its structure is shown in Table 1 as an example. Starting with column B and using the lines 1, 2 and 5-13, each column describes a used type-room. Line 1 states the zone type to be used. Line 2 defines the building standard of the zone and in lines 5-13 the base areas of the zones considered must be assigned to the cardinal directions. In principle, different assignments are conceivable. An exemplary assignment is the division of the base area according to the ratio of the oriented surface to the total enveloping surface. The necessary weather data sets can currently only be generated with the TRNSYS-Type 16e from the TRY format [2]. In the future this conversion will be integrated in SimSIA. The output is provided as *.csv files with either, the standard (decimal points) or the european formatting (decimal comma). Also *.npz files may be exported. The formats were chosen to allow easy access by the everyday user. The outputs are not in *.xlsx but in *.csv format, as this may be simpler for other software to use.

Table 1. Example of a building definition

	Column A	Column B	Column C
1	Usecase	N1.1_Wohnen MFH	N12.3_Treppenhaus
2	Type	Zielwert	Zielwert
		area	$[m^2]$
5	North	2951	328
6	Northeast	1222	136
7	East	354	39
8	Southeast	2073	230
9	South	1063	118
10	Southwest	1868	208
11	West	1417	157
12	Northwest	0	0
13	Horizontal	0	0

Either can easily be opened in Excel.

Program execution

First, the presence of results from previous simulation runs is checked for the requested type-rooms. If no results are found for a given weather file and type-room, the combination is simulated 27 times: For each building standard (existing, standard, target), a simulation is run for each major and minor direction, as well as for horizontal solar radiation. Each such result is scaled by floor area and then their individual quantities are either summed up (gains or demands) or averaged (temperatures).

Dependencies

The library depends on the following packages:

uncommon: openpyxl, pandas
standard: datetime, json, math, numpy, os, pathlib, and shutil

"openpyxl" and *"pandas"* might need to be installed using pip (the rest is part of the standard installations).

OUTPUT

As mentioned above, the present version of SimSIA provides the following result files: two *.csv files (international and European formatting) and one *.npz file for each type-room used. For multi-zoned buildings, the *.csv files contain area-averaged values for air temperatures and the required, specific, thermal load profiles for heating, cooling, and tapping hot water. Furthermore, internal loads, loads due to infiltration and ventilation, solar loads, and the electrical power demand of the ventilation system are provided. The *.npz files contain the same data, supplemented by the respective operative room temperature. This value could not be reasonably given as an average if there were a mixture of several type-rooms. Each power value is given as an area-specific value. To take simultaneity factors into account, a smoothing of the load peaks is possible as described above, whereby the parameterization of the smoothing has to be done by the user. Currently only the values associated with the heating of the building have been validated (see chapter Validation). The calculation of the cooling loads show larger deviations and thus work on this issue is still in progress (see chapter Future Work). The heating load for domestic hot water results from a profile linked to the presence of persons, which is why the values can only be considered plausible.

VALIDATION

Single-zone

To validate our model, four steady test cases are formed that build on each other:

1. transmission losses only
2. adding ventilation losses
3. adding internal gains
4. adding solar gains

Figure 2 shows the steady-state specific heating power per squaremeter for the different test cases and type-rooms. Since SimSIA does not consider sky temperatur as separate from the air temperature, for this comparison in TRNSYS, they were set equal. Comparing the results of TRNSYS and SimSIA, the cases described differ by less than 4 % on average.

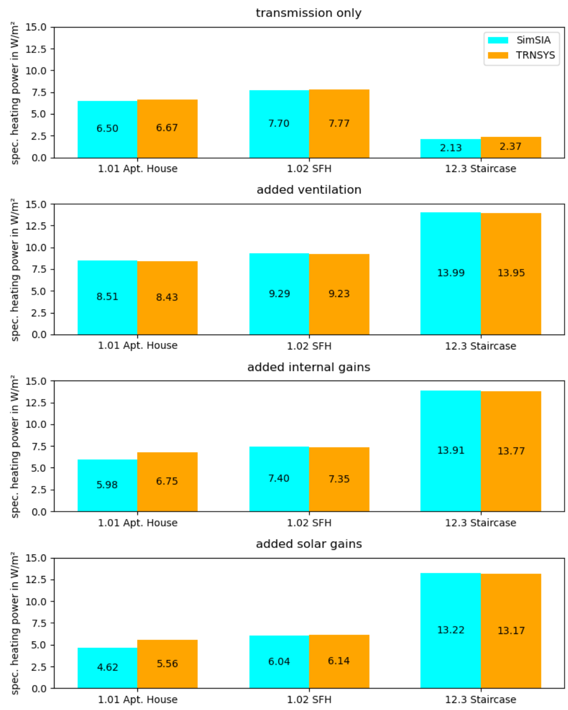

Figure 2. Comparison of steady-state simulation results obtained with SimSIA and with TRNSYS

Multi-zone building

A fairly common building in cities is an apartment building with a stairwell facing north. Therefore, a building was modeled with three floors 20 by 20 meters, and a 5 by 8 meters stairwell (N12.3) projecting into the center from the north. The remainder is N1.1 living space Fig. 3. In addition to the steady-state test cases described above, different years were simulated for this building, namely the test reference years 2010

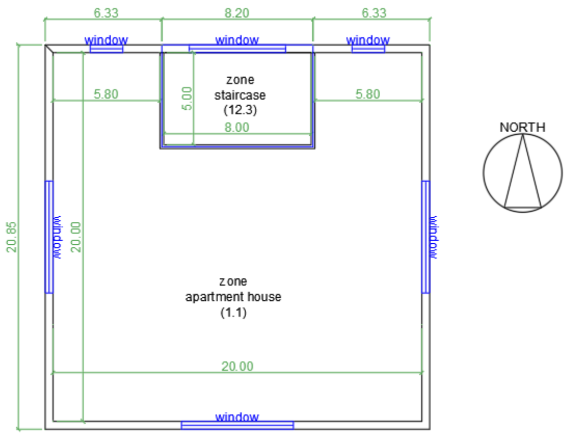

Figure 3. Modeled apartment house with staircase

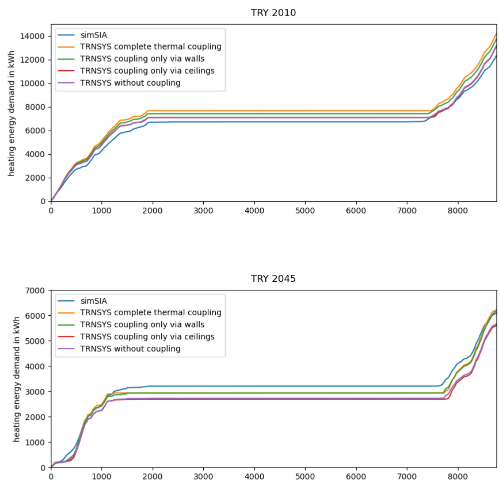

Figure 4. results for modeled multi-zone-building

and 2045 for a Stuttgart site. SimSIA does not consider the heat transfer between different zones. The influence of this simplification was investigated in TRNSYS. For this purpose, the full thermal coupling was gradually reduced to walls, ceilings and not present. Figure 4 shows the heating energy demand of the building as a meter reading curve. For both weather data sets, the SimSIA results over one year differ only slightly from the TRNSYS models.

ANALYSIS AND DISCUSSION

The approach presented can be considered validated by checking it with individual type-rooms and a model building. However, by modeling in TRNSYS different reasons for deviations of further (real) buildings could be shown:

1. The ratio of opaque exterior surfaces, window areas, and the floor area:
   SIA-2024 assumes a fixed ratio between these surfaces for each type-room. If this ratio does not coincide with the building considered, this will result in deviations between SimSIA and more elaborate models. This becomes especially relevant for buildings that are composed of different type-rooms or a different ratio of envelope area to volume. The reason is that the area ratio of the individual type-rooms can result in an envelope area that does not correspond to the envelope area or its distribution over the zones of the real building.
2. Other distribution of window areas:
   Since SIA-2024 considers the radiation coming from the west as equivalent to the average of all cardinal directions, the window areas of a type-room are oriented to the west. If the windows of the real building are oriented evenly this corresponds to the assumed distribution in SimSIA. However if the windows of the building are distributed unevenly, large deviations are to be expected.
3. Load curves deviating from the type-room:
   Deviations of the load curves for ventilation and internal loads between the real building and the type-rooms, result in corresponding deviations for the energy demand.
4. Strongly different temperature zones:
   In the case of the multi-zone building, it was shown that not taking into account the thermal coupling only has a minor influence on the energy demand. Here the temperatures of the two type-rooms were quite similar at 18°C and 21°C, respectively. If these are further apart, greater deviations are the result.
5. Equal treatment of ceilings and floors with walls in SimSIA:
   In SimSIA, the thermal envelope area does not distinguish between walls, ceilings, and floors. This results in different heat transfers and effective thermal response.

The required input data for SimSIA is easily obtained following SIA-2024. Furthermore, since the database is rather accessible, refinements can be made by the definition of new type-rooms or modification of existing ones. Simulation of type-rooms is only necessary once (pre-processing). Scaling the intermediate data to real buildings allows a very fast generation of results. If buildings consist of alreadey simulated type-rooms, this scaling is done instantaneously. This means that even entire city districts can be quickly modeled and simulated using this method. This is especially true when the level of detail, as is usual in early design phases, is not yet particularly high or if different variants are to be considered.

Processing time comparision

The presented approach claims speed improvements, that get better with larger numbers of buildings. This is rooted in the separation of the pre-simulation and scaling phase. Let us assume there are N buildings, with M type-rooms, but all different in floor plan and layout, as well as floor share for their uses. Modeled in a detailed simulation, each building needs to be both entered and simulated, individually, leading to amortized time demands (t_{dem}) of:

$$t_{dem} = O(M * t_{setup}) + O(N * t_{sim}) \quad (4)$$

Because in SimSIA the simulation has to be done only once per type-room and the scaling is separated from it, this becomes:

$$t_{dem} = O(N * t_{setup}) + O(M * t_{sim} + N * t_{scale}) \quad (5)$$

Since scaling is a single operation (multiply and add), it is exceedingly fast. As the pre-simulation only needs to take place once per type-room, changing the floor shares of buildings is instantaneous. Furthermore, setup time per building (t_{setup}) is significantly lower than a detailed building simulation due to the use of type-rooms in SimSIA. Based on the relationships shown and our assumptions for the various time requirements, the following time differences result, as seen in Fig. 5.

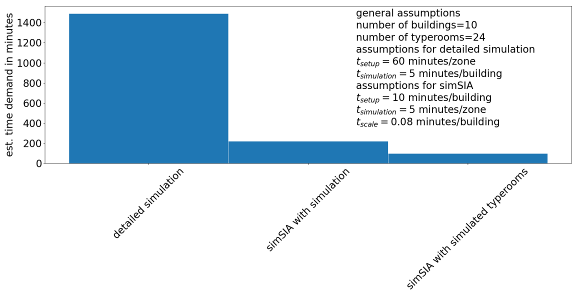

Figure 5. Comparison of processing time between SimSIA and a detailed simulation

SUMMARY

SimSIA provides a fast and scalable approach to simulating buildings on district level. The script is structured as a library but also provides a simple command-line interface. Therefore it can be executed directly from the command line or in batch. The presented approach implemented by SimSIA is capable of delivering results very fast. As intended, it is well suited for early planning. As shown, this approach (and its reference implementation in SimSIA) forms the often missing intermediate approach between computation and simulation. It provides a good approximation of what a refined model might show, without the need for the same effort as an in-depth simulation. At the same time, it provides more detail than a simple monthly balance.

FUTURE WORK

SimSIA is currently still in the development phase. The model validated so far only includes the calculation of the necessary heating power. A calculation approach for the cooling case is integrated, but could not yet be validated successfully. It may be necessary to modify the calculation approach to be able to deliver valid results for cooling as well.

A possible optimization would be the use of different metrics. Currently the floor area is used for scaling the loads. Especially for solar loads, which contribute significantly to the cooling demand, other metrics, such as the envelope area, could be better suited for scaling. Also a combination of different scaling metrics, e.g. internal loads based on the floor area and solar gains based on the envelope area are conceivable. The goal remains a tool that can be used in early design stage, where scarce knowledge about the buildings must be accounted for.

For ease of use, the automated reading of test reference years (TRY) as supplied by the german weather service (dwd) would be beneficial. Since the model requires irradiance values from all cardinal directions, currently a conversion from the global irradiance as contained in a TRY is necessary.

In the future, it shall be possible to take permanent shading of the building into account. Analogous to the monthly balance method according to DIN 18599-2, the reduction of solar irradiation with one factor for each cardinal direction shall be useable.

The smoothing of results can also be optimized: First by being able to adjust the smoothing parameters. Later on, possibly by calculating the smoothing parameters from technical quantities, such as the capacity of a buffer storage.

Investigations indicate that building geometries cannot provide valid results, if they differ to much from the type-rooms of the database, even after scaling. This problem will be addressed in future versions. Depending on the user and the parameters to be varied, graphical user interfaces (GUI) would facilitate the operation of the tool. Such a GUI could e.g. also include the calculation of variations on the same type-room, and a comparison of their results could be provided. Such variants could consider e.g. different set-point temperatures, the adjustment of ventilation, or sun shading control.

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