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1 Executive Summary

This report outlines two different approaches for setting up a renovation roadmap for an existing building in terms of energy saving measures implemented on the thermal envelope of the building. The two approaches are denoted the expert approach and the analytical approach. The expert approach is like what is found in most European energy certification schemes i.e., an expert evaluates the buildings energy performance and suggests energy upgrading measures based on the inspection, physical conditions of the building, national or regional building tradition and building materials. This results in recommendations for energy upgrading with accompanying energy savings and realistic costs. In the analytical computer power is being used to carry out multiple simulations of different energy upgrading actions within pre-defined limitations for each upgrading action. In this way it is possible to identify the solutions and combination of solutions that result in the optimum key performance indicator(s) (KPI) selected for the task. However, as building energy upgrading costs are not linear it is not possible to use this method to calculate costs related to all the combinations considered in the simulations. This shows that the two methods can supplement each other where the analytical approach can identify the optimal solution(s) for achieving the best KPI, the expert approach can provide realistic cost estimates for the selected solutions.

2 Introduction

This report outlines two different approaches for developing a renovation roadmap for a given building, exemplified by selected case study blocks of flats. The two approaches can be denoted the expert approach and the analytical approach.

The practical expert approach is like what is found in the development of many energy performance certificates (EPC) in the national European building energy certification schemes. It is thus the building assessor that, after a physical visit to and inspection of the building, evaluates which renovation actions is suitable for the actual building. This is done based on existing conditions, possible space for additional insulation, the type of building constructions, and national building tradition and costs. The number of analysed renovation actions are thus limited to the most probable actions and in addition actions that meets national requirements.

The analytical approach or PREDYCE approach, on the other hand, relies on computer power and a large number of variations for each renovation action. As examples, the insulation thickness on the attic can be increased linearly or windows can be selected among a limited number of window types for replacement of the existing ones. There is though one challenge regarding this approach, and that is the non-linearity of costs. Costs do not depend on e.g., the insulation thickness as a continuous cost function. At certain insulation thicknesses, additional works and/or additional supporting material is needed to mount the insulation, causing a jump in the cost. Therefore, these sensitivity analyses are in this context linked to the indoor comfort (temperature and CO_2) level in the modelled building.

2.1 Expert approach

The base for the expert approach are the building models that have been developed in WP2 and documented in the preliminary version of D2.3, to investigate the influence of the level of detail for the building models on the simulated energy performance. For the renovation roadmap the most and the least detailed of these models are used, i.e., models where each room is represented by a thermal zone (Figure 1), and models where all flats are grouped together into one single thermal zone (Figure 2).

Costs are extracted as information from the Danish national cost index Molio 2022 cost database version 7.1.5.12552 [Mol22] with gross costs including profit. The renovation costs include material and labour costs plus additional costs, e.g., for scaffolding and additional needed follow up works related to each renovation action.

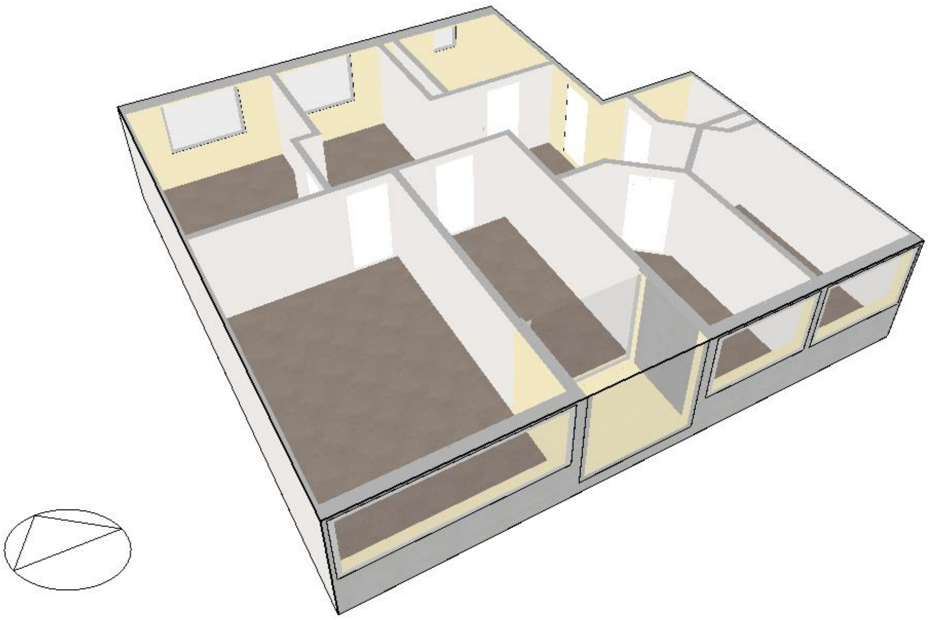


Figure 1 All rooms are represented as individual thermal zones, here shown for one flat only.

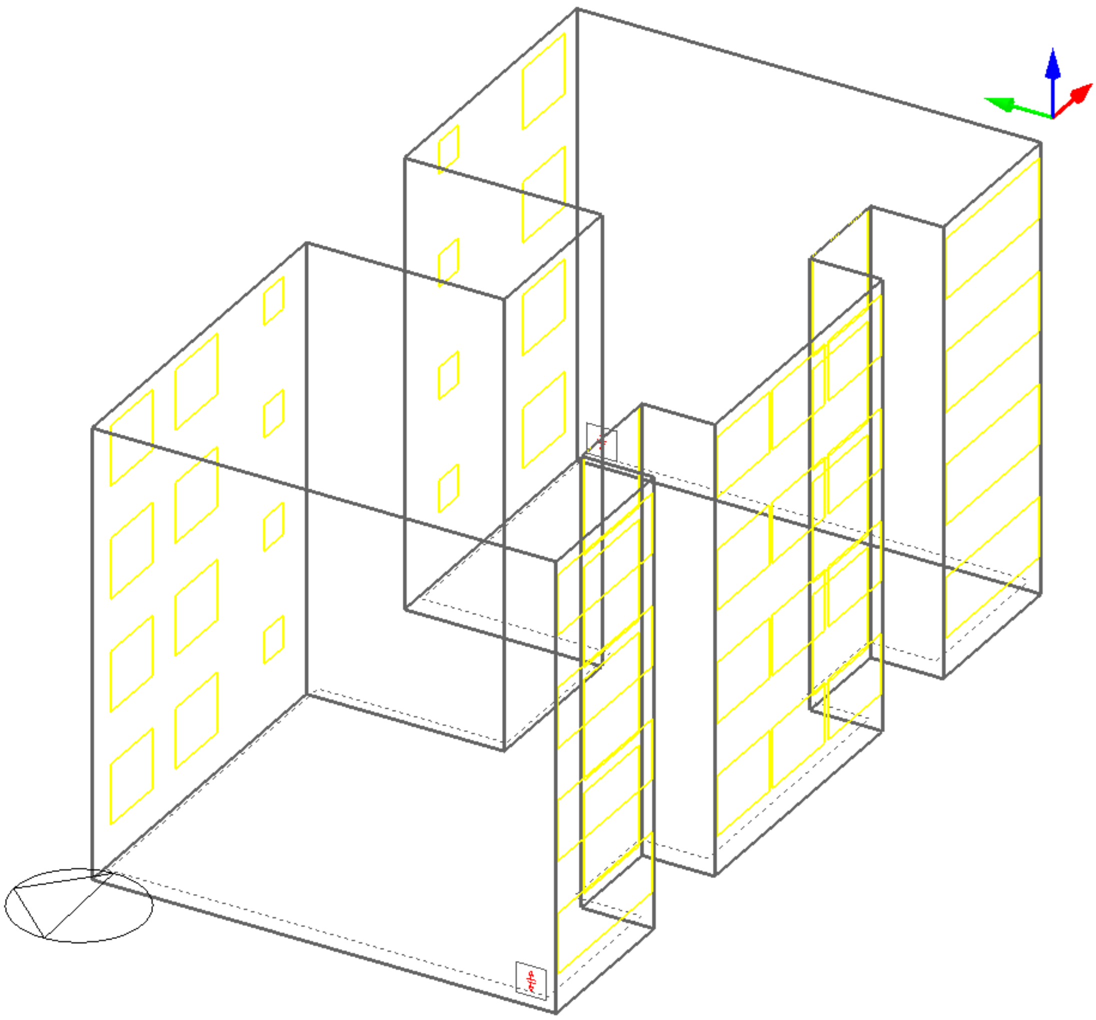


Figure 2 All rooms at all levels are grouped as one single thermal zone for the entire building.

2.1.1 Cost efficiency calculations

The cost efficiency parameter (CEP) indicates the cost per lifetime year for the saved energy per energy unit, here kWh, and should be compared with the cost for purchasing energy:

$$\text{CEP} = \frac{\text{Investment [€]}}{\text{Annual energy savings [kWh] * Lifetime of measure [years]}}$$

This indicator does not include evolution of capital cost or energy price, but for the purpose of comparing actions to select the most cost effective this simplification is largely acceptable and rarely leads to wrong decisions.

2.1 PREDYCE retrofitting methodological approach

The PREDYCE platform – described in detail in the E-DYCE deliverables 3.1 and 3.2 [Chi22b & Chi22b] – can act as enabling platform supporting professionals in analysing the impact of retrofitting choices on building energy and comfort indicators. This Section presents an approach to use this Python [Pyt22] library to help retrofit analyses with its application to the same E-DYCE demonstration cases adopted for the other sections of this deliverable.

The dynamic simulation platform allows, in fact, for quick and simple massive sensitivity analysis on main design parameters. Figure 3 highlights which steps of the process can be automated through PREDYCE (which includes other usage scenarios besides sensitivity analysis) and run in the backhand, but also the steps requiring human effort. Plot production can be partially automated. Still, it remains open to personalisation by exploiting structured CSV output files from the KPIs calculator module: this allows for deep analyse of the results according to users' basic programming capabilities. As shown in this figure, the input files for this PREDYCE usage scenario are the EnergyPlus [EPlu22] inputs (IDF and EPW files) and the PREDYCE managing file (JSON).

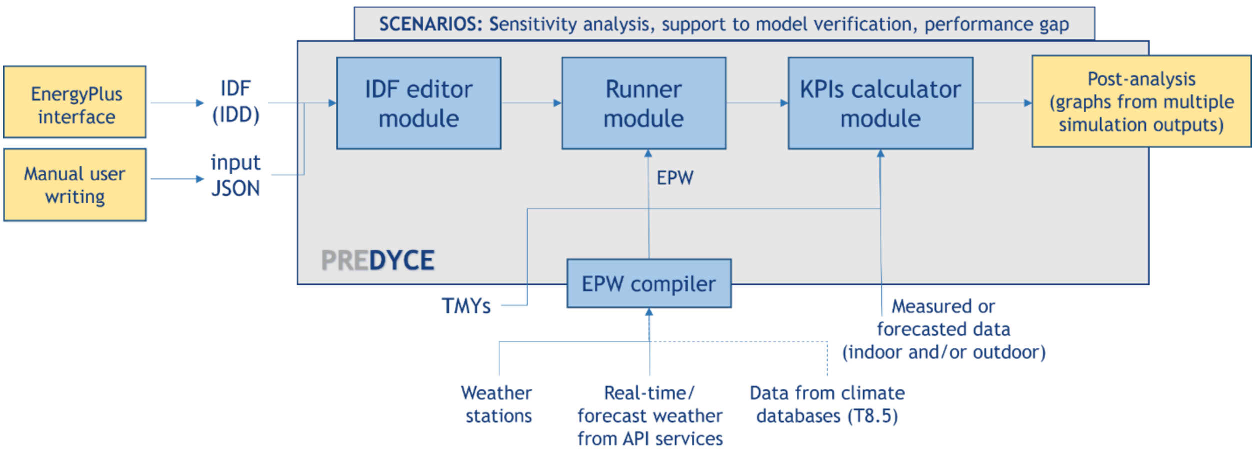


Figure 3: PREDYCE workflow: the grey box highlights automatic functionalities running in the back end concerning the end user; the yellow boxes highlight not-automated steps requiring human interaction.

For this analysis, the tool sensitivity scenario is adopted, allowing IDF modifications (the EnergyPlus input file) contents and objects according to chosen actions – e.g., adding external thermal insulation to boundary walls – and defining variation ranges of selected values (e.g., changing the thickness of the thermal insulation layer by expressing this variation as a list of values or as variation range with a given step). Figure 4 shows a sample extract from the JSON file that supports the action mentioned above (*add_external_insluation_walls*) with a given list of additional insulation thicknesses.

```
"add_external_insulation_walls": {
    "ins_data": [
                    ["XPS Extruded Polystyrene CO2 Blowing",
                     "Gypsum Plastering"]
    ],
                "Thickness": [0.05, 0.10, 0.15, 0.20, 0.25, 0.30]
}
```

Figure 4: Example of input JSON file action

PREDYCE allows the combination of multiple retrofitting actions via the massive run of parametric simulations to support architects and additional users in analysing the impact that different design decisions will have on the simulated building energy and comfort performances using the defined set of indicators. Six hundred simulations per demo model have been implemented for this deliverable in the following testing applications.

The use of the PREDYCE tool for retrofitting scenarios can retrieve the following list of analyses and correlated results:

- for all simulations, the aggregated/average KPIs for the whole simulation period (run period) allow for a fast comparison between scenarios (a CSV file in which each row is a simulation);
- time-series results for all simulations, allowing for a deeper comparison among scenarios that may be elaborated at different granularity (e.g. daily, hourly, timestep)
- specific graphs for single simulations elaborated by the ”KPI-calculator-module” showing KPI distributions – see the samples in the sub-sections below – including the future possibility to increase the number of pre-defined graphs and/or to aggregate more than one simulation in the same figure;
- heat map analyses that summarise all results of the whole simulation matrix (all simulations), allowing the professionals to make early-design decisions.

Especially the latter is a very innovative possibility offered by PREDYCE concerning other tools since it allows extracting from the whole simulation set the statistical impact that a specific retrofitting action has on the chosen list of KPIs. By this analysis, it is possible to select or prioritise the ones that better increase the expected building performance, helping early design decisions.

The possibility of running the whole process on the same building model used for the other E-DYCE steps (i.e. DEPC development, Performance Gap detection, …) allows optimising times and costs. This possibility is aligned with the rationale described in the E-DYCE Deliverable D1.2 [Chi20] and detailed in the DEPC protocol in Deliverable D2.4 [Kal20] adding to the base E-DYCE methodological process also extra functionalities, such as the one here described.

3 Expert renovation roadmap

3.1 Case building Hånbaek

The expert renovation roadmap is based on Danish minimum requirements for building energy upgrading in combination with planned renovation actions and knowledge about building tradition and standard values for materials. As a starting point, a model of the section of the building being investigated was set up, and in the following denoted the AsIs model.

AsIs: The building has been upgraded since it was constructed in the 1960'es, which includes replacement of windows and attic insulation. **Windows** are replaced within the last 10-15 years and have a U-value of 1.8 W/m²K, so replacing the windows or glazing will result in significant energy savings. The **attic** has been upgraded to a total insulation thickness of 275 mm and a surface-to-surface thermal resistance of 6.67 m²K/W. Additional insulation will thus have limited impact on the overall energy performance. Floors towards the **basement** are insulated with 5 cm insulation below the floor boarding with a surface-to-surface thermal resistance of 1.53 m²K/W. Additional insulation at the basement ceiling will thus have an impact on the overall energy performance as well as the thermal comfort at the ground floor flats. **External walls** are pre-cast concrete elements with 50 mm insulation and a surface-to-surface thermal resistance of 1.31 m²K/W. Addition of external insulation will thus have a significant impact on the overall energy performance of the building. The cost of installing **photovoltaic** (PV) systems on existing buildings with inclined roof is often a cost-efficient energy upgrading measure and should be investigated.

Glazing: If the frames of the existing windows are sound, replacement of the glazing may prove to be a cost-efficient energy renovation measure. New glazing will provide a centre U-value of less than 1.0 W/m²K, which will reduce the heat-loss through the glazing by a factor 2. Naturally, it is a prerequisite that the frame is sound and is of adequate dimension to carry the new glazing. Costs include removal of the existing glazing, delivery, and installation of new glazing in the existing frames plus scaffolding for the entire working period.

Windows: Normally, it is not cost-efficient to replace windows unless they are worn and needs replacement anyhow. Replacement for energy saving only, is not cost efficient unless the existing glazing is single pane. New windows will provide a centre U-value of less than 1.0 W/m²K, which will reduce the heat-loss through the glazing by a factor 2. Only one type of glazing is analysed as the selected type is the required minimum energy performance for replacement of glazing/windows in Denmark. Additionally, this energy performance of the windows is the type of lowest cost as it is equal to the minimum requirement for windows in both new and existing buildings. Additionally, it is near the best possible option on the market within a reasonable cost. Costs include removal of the existing windows, delivery, and installation of new windows plus scaffolding for the entire working period.

External wall insulation: The existing facade only have 50 mm insulation material between the two concrete slabs. Renovation measures, applying 125-, 200-, and 250-mm external insulation respectively, are considered. All insulation thicknesses are covered by a layer of plaster. Costs include delivery and installation of insulation material and plaster, scaffolding plus creation of a new window framing and aligning windows with the insulation layer. *In case of combination measures with replacement of windows, the latter cost needs to be eliminated.*

Attic insulation: Even though the existing attic insulation have a thickness of 275 mm additional 100 mm of insulation is analysed as an energy upgrading option. This is done as 300-400 mm of insulation in the attic is minimum for renovating existing buildings in Denmark if it is economic feasible. Cost includes blow-out insulation, rising of the attic floor and skirting boards towards the roof-floor joint.

Basement insulation: We assume there is sufficient ceiling height in the basement and 100 mm ceiling insulation can be installed. The cost includes insulation material and installation plus gypsum board covering of the insulation material.

PV: Installation of PV on the south facing side of the inclined roof has been analysed as three different system sizes i.e., 32.5, 65, and 97,5 m² PV area, respectively. The reason for choosing these sizes, is due to availability of prices for these sizes in the cost database. The cost of the PV systems includes delivery and installation of the systems, which includes inverters and scaffolding.

3.1.1 Monthly method, stationary

The monthly (quasi stationary) method used when calculating the renovation roadmap is the official Danish energy performance certificate calculation engine Be18 [Agg18]. Calculation of the heating and cooling demand in B18 is based on EN ISO 13790:2008 [DS08]. Heat production and losses from installations is based on relevant European standards.

In the monthly calculations, the entire building is modelled as one single zone with the same average indoor climate and distribution of solar gains from south to north facing rooms. Heat capacity of internal walls and floors are treated as a single node with a heat capacity equal to that of the internal walls and floors if all rooms had been modelled as individual zones.

Table 1 Renovation measures, accompanying costs and cost efficiency for single zone model in monthly method.

Variation	Heating kWh	Cost €	Savings/ Production kWh	CEP €/kWh
AsIs	53514	-	-	-
Glazing	49134	160363	4444	0.16
Windows	49134	316026	4444	0.32
Facade insulation 125 mm	48086	601758	5506	0.36
Facade insulation 200 mm	47324	733044	6279	0.39
Facade insulation 250 mm	47039	794496	6569	0.40
Attic insulation	53133	67019	386	0.58
Basement insulation	49324	266536	4250	0.21
PV 32.5 m²	53514	111571	2952	0.20
PV 65 m²	53514	215566	5904	0.19
PV 97.5 m²	53514	317940	8855	0.19

3.1.1.1 Calculation assumptions differing from dynamic simulations

Besides the simplicity of the calculations vs the simulations there are differences in the perception of heat losses from the building to unheated spaces. In the simple calculations, heat-loss to unheated spaces is attributed a loss of 70% compared to losses to the outdoor. In the dynamic simulations, the unheated spaces are simulated as separates zones, hence having varying temperatures and resulting in a varying heat-loss from the heated space(s). Additionally, the simplified calculations include energy use for domestic hot water, which is not taken as part of the calculated heating demand. However, heat losses from the DHW installations passing through the heated space contributes to the space heating but is attributed the energy use for DHW production.

3.1.1.2 Time needed

It is assumed that it will take approx. 2 hours to set up a model and make the AsIs calculation of the building. Any additional calculated scenarios will take approx. 10 minutes.

3.1.2 One zone dynamic model

In the one zone building model, all apartments are modelled as one single zone with the same indoor climate and even distribution of solar gains from south to north facing rooms. Attic and basement are modelled as two separate, unheated rooms. Heat capacity of internal walls and floors are treated as a single node with a heat capacity equal to that of the internal walls and floors if all rooms had been modelled as individual zones.

Table 2 Renovation measures, accompanying costs and cost efficiency for single zone model.

Variation	Heating kWh	Cost €	Savings/ Production kWh	CEP €/kWh
AsIs	45495	0	0	0.00
Glazing	41650	21382	3846	0.19
Windows	41650	42137	3846	0.37
Facade insulation 125 mm	36210	80234	9286	0.22
Facade insulation 200 mm	36167	97739	9329	0.26
Facade insulation 250 mm	36123	105933	9372	0.28
Attic insulation +100 mm	45142	8936	353	0.63
Basement insulation	44492	35538	1003	0.89
PV 32.5 m²	45495	14876	5331	0.11
PV 65 m²	45495	28742	10829	0.11
PV 97.5 m²	45495	42392	16243	0.10

In the cases above the is both reduction of thermal energy and production of electricity. The average cost for district heating, as the building takes, in Denmark ranges from 0.05 €/kWh to 0.25 €/kWh. So, the renovation roadmap needs to be constructed based on the energy price by the actual district heating company. The average electricity price in Denmark (August 2022) is above 0.47 €/kWh, hence all sizes of PV installations are profitable if electricity can be used behind the meter. However, the feed in tariff varies between 0 and 0.08 €/kWh and this dramatically reduces the profitability for locally produced electricity if exchanging with the grid. Nevertheless, all PV installation sizes seems to be profitable in this building, especially as this is a multi-family building with a more uniform electricity use over the day, compared to single-family houses.

3.1.3 Multi-zones dynamic model

In this model, every room is modelled as an individual zone. Internal heat capacity is thus distributed to the rooms where solar enter the building through windows with limited possibility to let the stored energy transfer from warm to cooler zones. The indoor thermal climate is thus expected vary more than in the building model with one zone for the entire building. Heating need is thus expected to increase as north facing rooms may call upon heating while south facing rooms have surplus heat from the sun.

The same energy saving measures and costs are assumed for the calculations in this model as in the single zone model. Costs for measures with PV installation is therefore the same for the two model.

Table 3 Renovation measures, accompanying costs and cost efficiency for multi-zone model.

Variation	Heating kWh	Cost €	Savings/ Production kWh	CEP €/kWh
AsIs	36983	-	-	-
Glazing	31337	21382	3.78	0.13
Windows	31337	42137	7.46	0.25
Facade insulation 125mm	33809	80234	25.27	0.63
Facade insulation 200mm	33384	97739	27.14	0.68
Facade insulation 250mm	33189	105933	27.91	0.70
Attic insulation	36487	8936	18.03	0.45
Basement insulation	35523	35538	24.33	0.61
PV 32.5 m²	36983	14876	2.79	0.11
PV 65 m²	36983	28742	2.65	0.11
PV 97.5 m²	36983	42392	2.61	0.10

3.1.4 Expert renovation roadmap summary

Having calculated energy savings for three different levels of model detail i.e., monthly single zone, single zone dynamic and multi-zone dynamic, some observations can be made:

- replacement of glazing gives similar results for the monthly and the detailed dynamic model
- additional insulation of the facade gives similar results for the two dynamic models
- additional insulation towards unheated zones (basement or attic) shows inconsistent results
- additional insulation towards the basement seems to be overestimated in the monthly model, probably due to the handling of heat losses to the basement (underestimation of the basement temperature)
- installation of PV does in all models give some of the best cost efficiency for improving the energy performance of an existing building, compared to upgrading of the thermal envelope

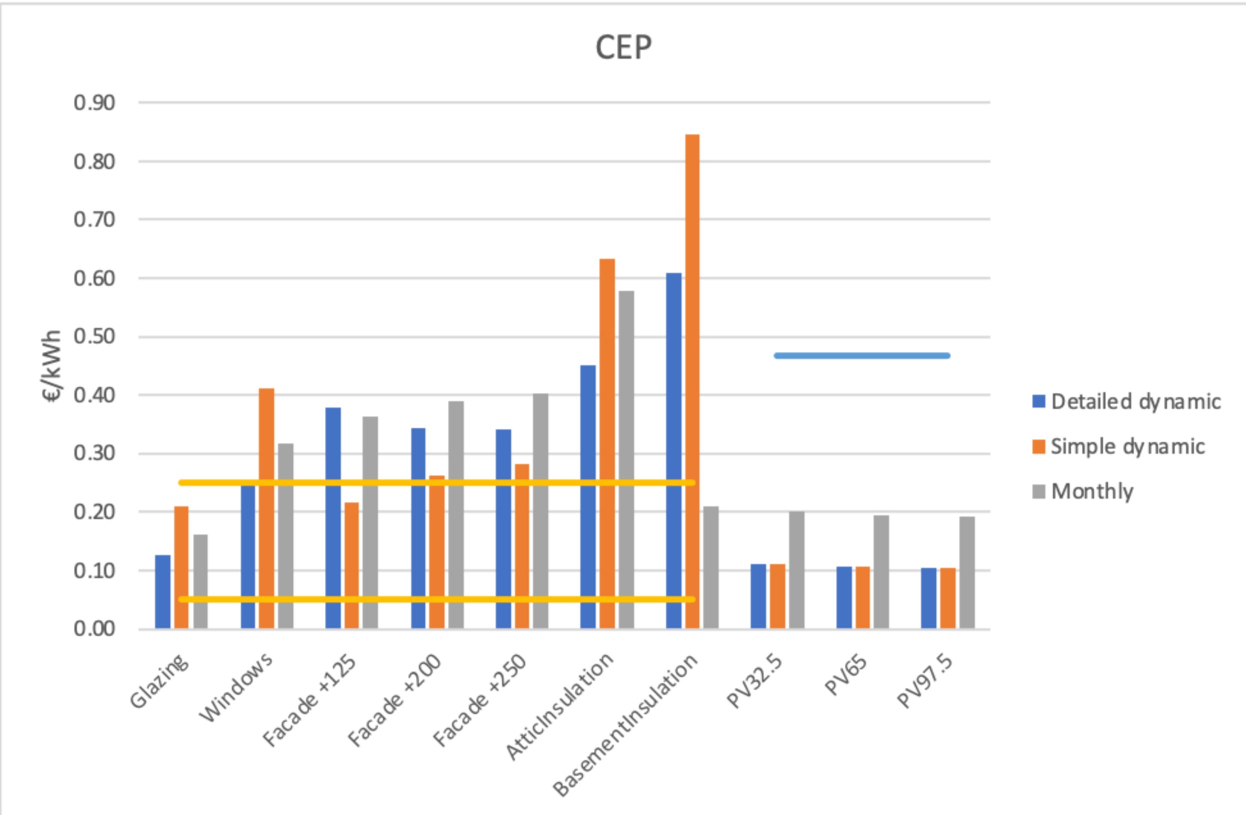


Figure 5 Cost efficiency parameter [€/kWh] for three different model detail levels applying the same energy saving measures. Horizontal lines represent the price span for district heating (yellow) and average electricity price (blue), respectively.

3.2 Case building Magisterparken

PV has already proved to be one of the most cost-efficient measures to increase the energy performance of an existing building with reasonable insulation levels of the thermal envelope, and no studies of this technology will be applied to the Magisterparken case building.

The external facades at Magisterparken are made of cavity wall brickwork and in its initial stage, without cavity insulation. That, in combination with a general reluctance of applying external facade insulation on brickwork, result in a decision to only evaluate cavity insulation as a possible measure for energy upgrading of the external walls. In addition, it is normally not considered economical feasible to apply external (or internal) insulation to a brick cavity wall with insulation in the cavity.

Only the summary results for energy upgrading measures at Magisterparken are shown Figure 6, as it follows the same principles as shown for Hånbaek.

Results generally indicate that annual energy savings are lower for higher detail level of the calculation models when analysing glazing upgrading. All models show CEP values below the cost for district heating when it comes to cavity wall insulation and attic insulation. For insulations towards the unheated basement the dynamic models show significantly higher CEP values than the stationary calculation. Again, this can be attributed the way heat losses to an unheated space like a basement are treated in the calculation model i.e., a fixed percentage of the heat loss to the ambient. In contrast, the dynamic models model the basement as a separate zone with its own dynamic temperature profile.

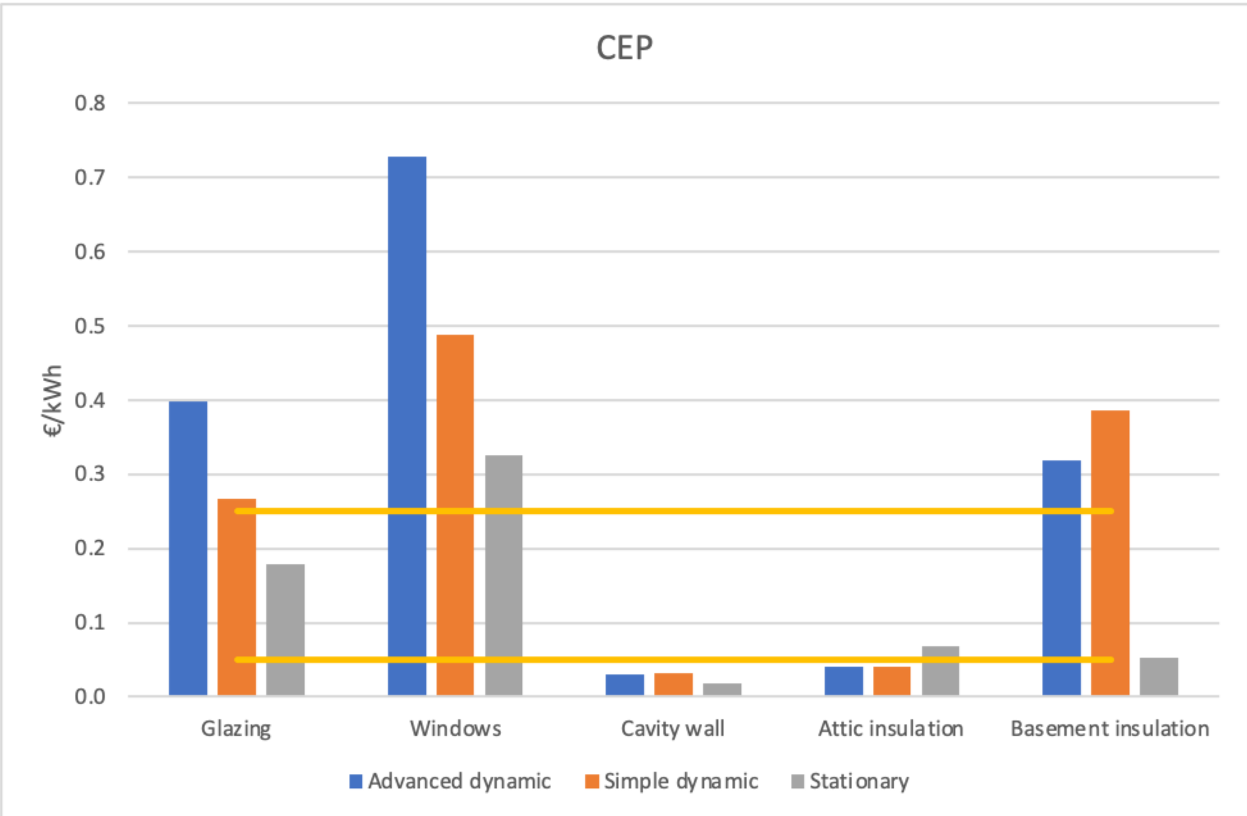


Figure 6 Cost efficiency parameter [€/kWh] for energy saving measures at Magisterparken. Horizontal lines indicate the hi and low price for district heating in Denmark.

4 Testing the PREDYCE functionalities in AAU demo cases

4.1.1 Input/output definition (JSON file)

PREDYCE functionalities have been tested on two Danish models of Hånbaek (B) and Magisterparken (A and B), studying the impact of different retrofit solutions on several KPIs, such as heating consumption and indoor thermal comfort, considering the PMV/PPD model for the heating season and the Adaptive thermal Comfort Model (ACM) for the free running season. All simulations have been performed adopting the same EPW file for Aalborg airport TMY.

Particularly the considered retrofit actions and the correlated variations of parameters are:

- Adding external thermal insulation to boundary walls in the range [0.05-0.30] m with a 0.05 m step;
- Adding thermal insulation on the roof floor in the range [0.05-0.25] m with step 0.05 m;
- Adding thermal insulation on the basement ceiling in the range [0.05-0.25] m with step 0.05 m;
- Substituting windows glazing system considering four options detailed by Ufactor, SHGC and visible transmittance values (Figure 9) referring to a general Triple LoE with Argon glazing system, a Double LoE Argon, a Double Clr Air, and a single glazing solution:


```
{"UFactor": 0.786, "Solar Heat Gain Coefficient": 0.474, "Visible Transmittance": 0.661},
{"UFactor": 1.493, "Solar Heat Gain Coefficient": 0.568, "Visible Transmittance": 0.745},
{"UFactor": 2.708, "Solar Heat Gain Coefficient": 0.703, "Visible Transmittance": 0.781},
{"UFactor": 5.778, "Solar Heat Gain Coefficient": 0.819, "Visible Transmittance": 0.881}
```


Figure 7: Adopted window glazing systems

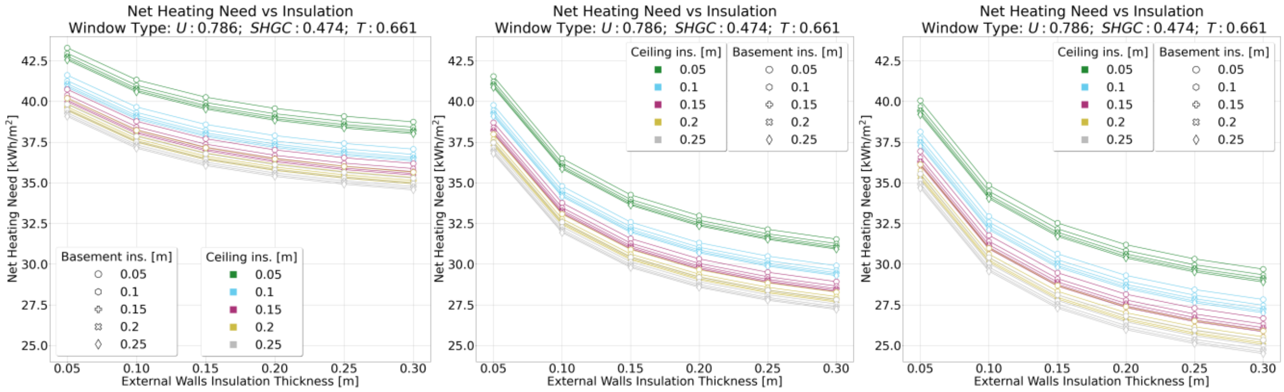
The computed KPIs are instead expressed in the following:

- Q_h: heating energy uses in kWh/m^2
- energy signature: 1D and 2D plots of weekly aggregated heating energy uses concerning outdoor conditions (temperature and global horizontal solar radiation)
- t_op: indoor operative temperature
- POR: Percentage Outside the Range (number of hours) considering PMV threshold of abs (0.7) correspondent to a PPD percentage of about 20% – see ISO 7730 and EN 16798-1
- cat *x*: number of hours in each of ACM categories – EN 16798-1
- dist: distance from ACM comfort line (category for each hour in the free running season)

4.1.2 Multi-simulation results and comparison

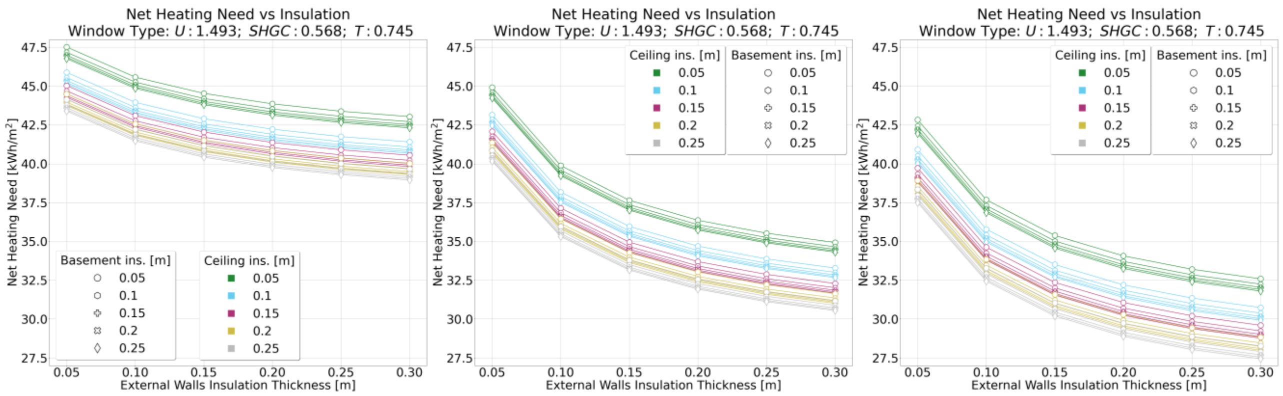
Results obtained from the 600 simulations performed for each building model can be easily visualised through different plots, allowing end-users to better understand the retrofit solutions' impact on various KPIs. The following plots have been obtained in post-analysis exploiting structured files obtained in output from PREDYCE and are not directly generated through the tool itself.

Figure 8, Figure 9, Figure 10, and Figure 11 show the impact on heating energy uses of all possible retrofit choices. Such as expected, higher thermal insulation will reduce the heating needs, underlining how external wall and roof insulations have a considerable impact. Similarly, the passages from highly insulated glazing systems with respect to old solutions (e.g., single glazing or simple double glazing) also strongly impact the heating energy needs. Additionally, the limited but visible difference between Magisterparken model A and model B results with all retrofit parameter combinations can be mentioned. The reason should be found in the different zoning approaches adopted in the two cases: in model A each building room is modelled as a separate thermal zone, while, in model B, the apartments are considered as one big thermal zone. Energy needs in the second case seem to be slightly underestimated with respect to the zoning approach adopted in model A.



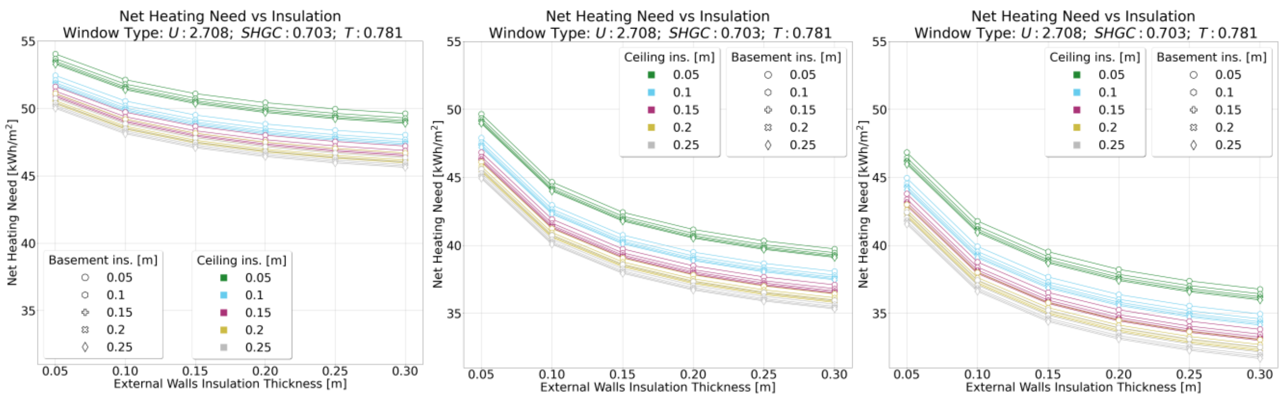
(a) (b) (c)

Figure 8: Heating consumption versus insulation with Triple glazing Arg LoE in (a) Hånbaek B, (b) Magisterparken A and (c) Magisterparken B



(a) (b) (c)

Figure 9: Heating consumption versus insulation with Double glazing Arg LoE in (a) Hånbaek B, (b) Magisterparken A and (c) Magisterparken B



(a) (b) (c)

Figure 10: Heating consumption versus insulation with Double glazing Air in (a) Hånbaek B, (b) Magisterparken A and (c) Magisterparken B

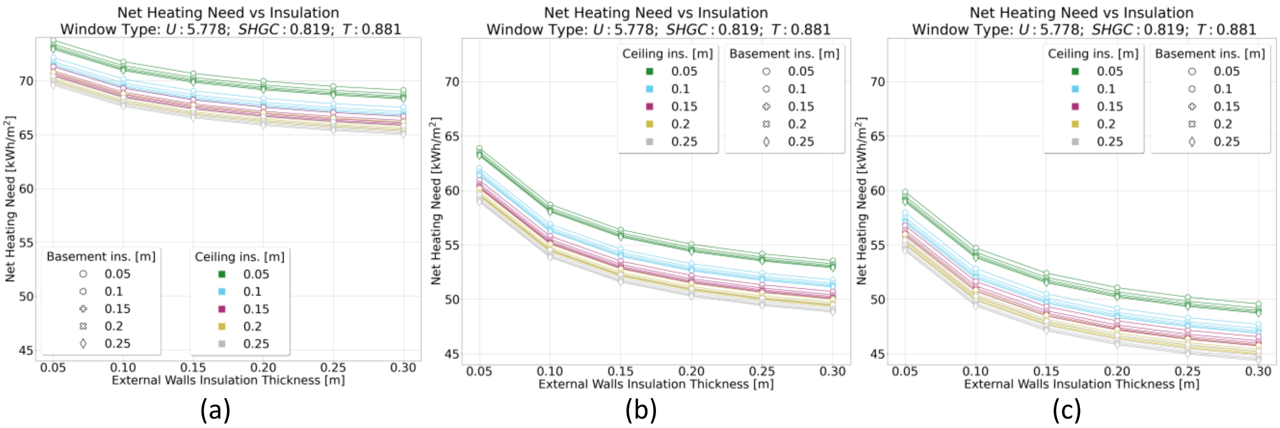


Figure 11: Heating consumption versus insulation with Single glazing in (a) Hånbaek B, (b) Magisterparken A and (c) Magisterparken B

Figure 12 reports the afore mentioned heatmaps. These graphs allow easily visualising each retrofit choice's linear impact concerning all the considered KPIs (both energy uses and indoor thermal comfort). It can, for example, be mentioned that for Hånbaek B, the glazing U-factor and the SHGC are drastically impacting the number of free-running hours (summer season) located in the adaptive thermal comfort category III (upper boundary). Mainly, signs in the heatmap should be interpreted as: "plus", if the increase of a specific parameter value leads to an increase in the KPI value, and "minus", if vice-versa. So, an increase in the U-factor or SHGC values for windows leads to increased energy needs, while in the summer to a decrease of hot hours located in ACM cat. III and upper.

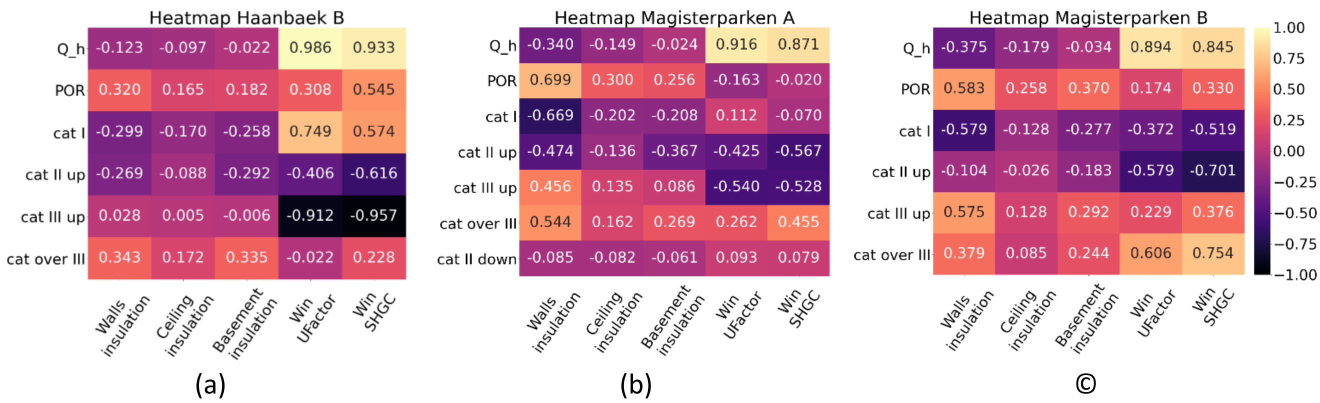


Figure 12: Heatmaps showing the impact of retrofit parameters on considered KPIs in (a) Hånbaek B, (b) Magisterparken A and (c) Magisterparken B

Finally, Figure 13 gives an example of the monthly distribution of the heating energy needs considering different wall insulation thickness variations. These plots may help analyse the impact over time that a retrofitting choice variation may have on a given KPI. Similarly, by assuming seasonal efficiency factors, these monthly values may be connected with EPC monthly based analyses.

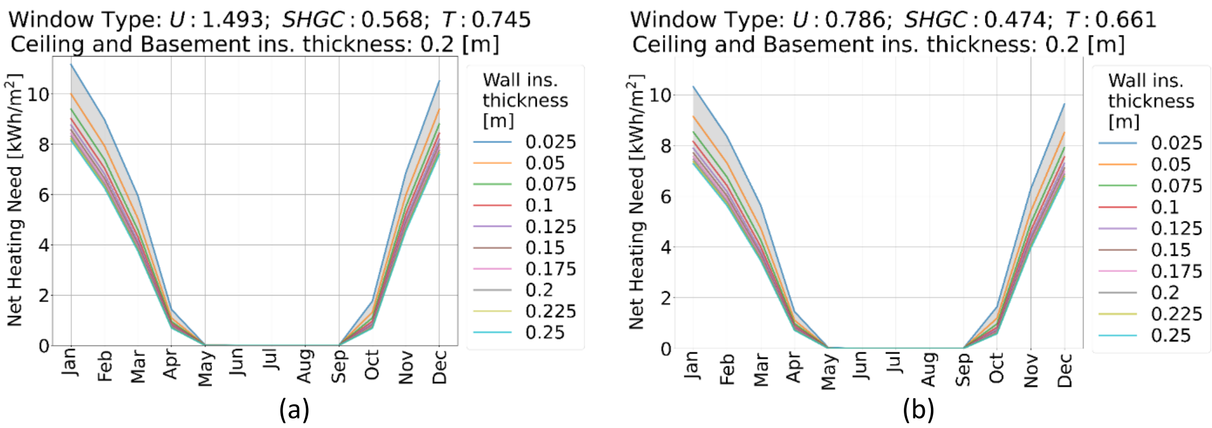


Figure 13: Monthly heating consumption versus walls insulation in Magisterparken A considering 20 cm of insulation on the roof and basement and in (a) Double glazing Arg LoE while in (b) Triple glazing Arg LoE

4.1.3 Single simulation results

In order to give an example of additional analyses and plots that may be retrieved via the PREDYCE platform, two Magisterparken A retrofitting case scenarios have been deeper considered:

- a case near the current building condition: no additional insulation on boundary walls, ceiling and basement and double Arg LoE glazing system;
- a case near the optimal retrieved solution: 20 cm of insulation added to boundary walls, ceiling and basement and triple Arg LoE glazing system.

Figure 14 compares the energy signatures calculated for the two solutions: the improvement given by the retrofit choices is evident both from the energy need values and the slope.

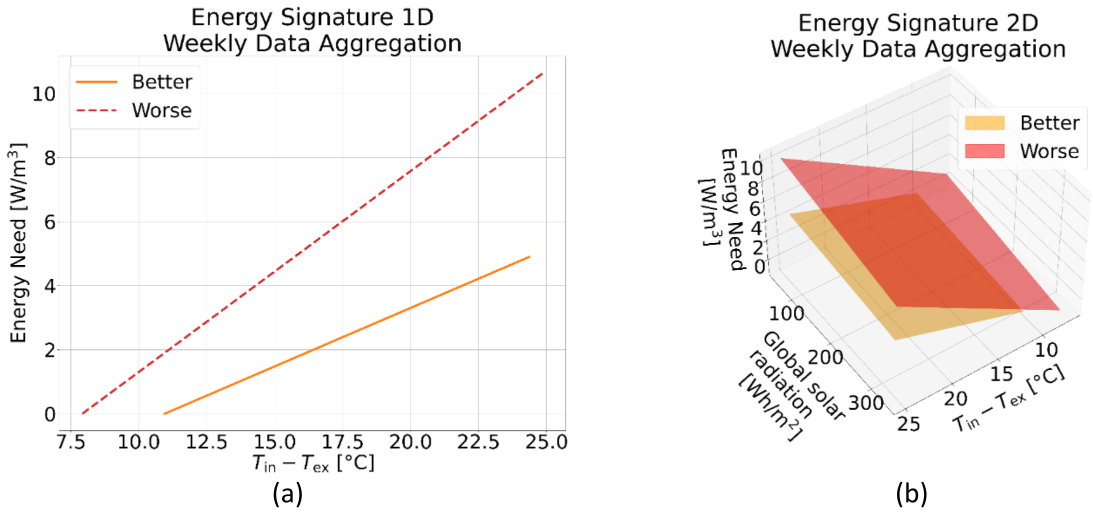
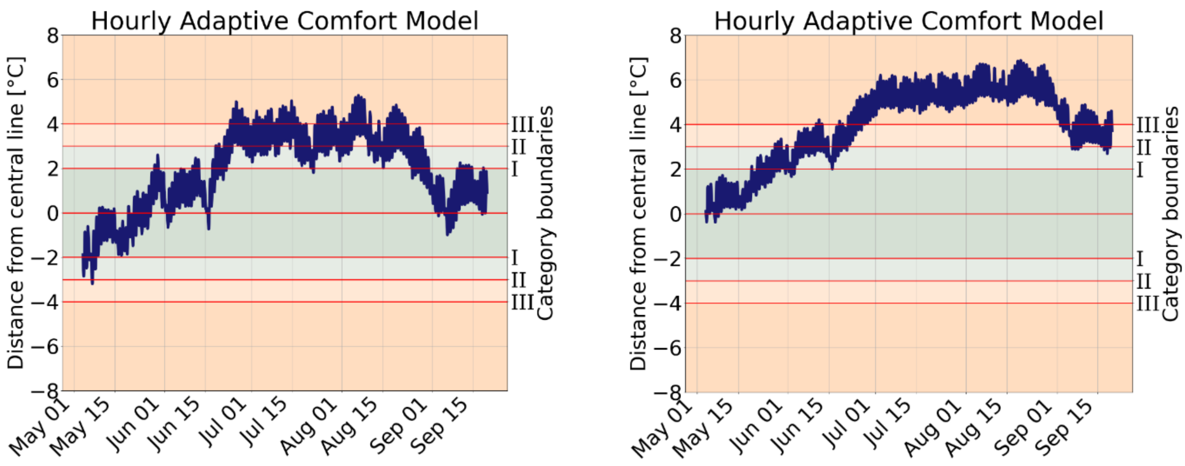


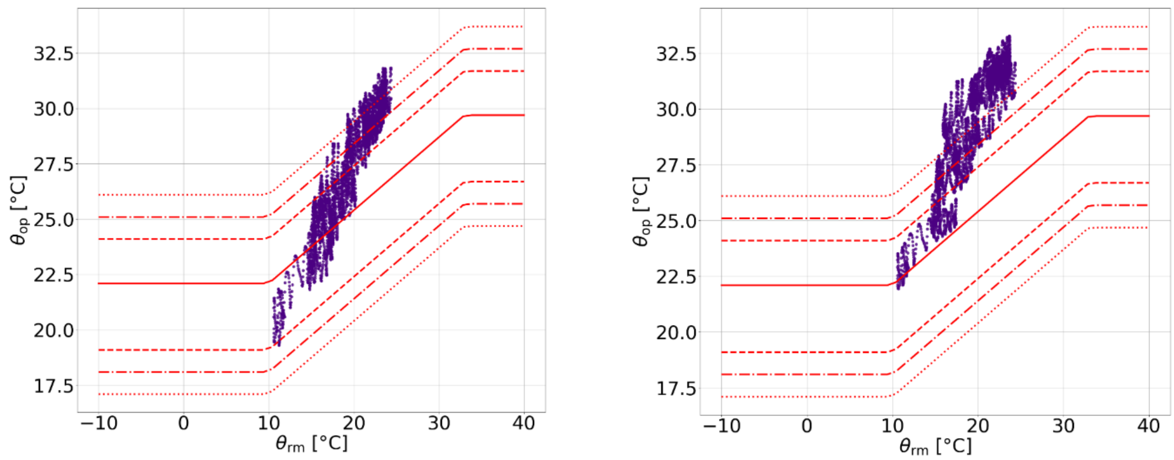
Figure 14: Energy signatures 1D (a) and 2D (b) for the two considered cases

Figure 15 and Figure 16 instead show, with different graphical approaches, the results for the adaptive comfort model in the two chosen cases. Graphs show the distribution of points per category in each hour of the free running season and the total points distribution in the categories for the whole season. It is evident how the considered additional insulation can generate overheating in the summer season, but an improvement in the intermediate months. The better case (b), defined based on a yearly analysis, is, although increasing the overheating risk in summer requiring for countermeasures. Other analyses could be performed to find the best balance between reducing heating energy needs and indoor comfort in the hot season. Eventually, the effect of shading system variations or ventilative cooling technologies may be tested with the PREDYCE tool to verify if these additional overheating risks may be solved by natural means.



(a) (b)

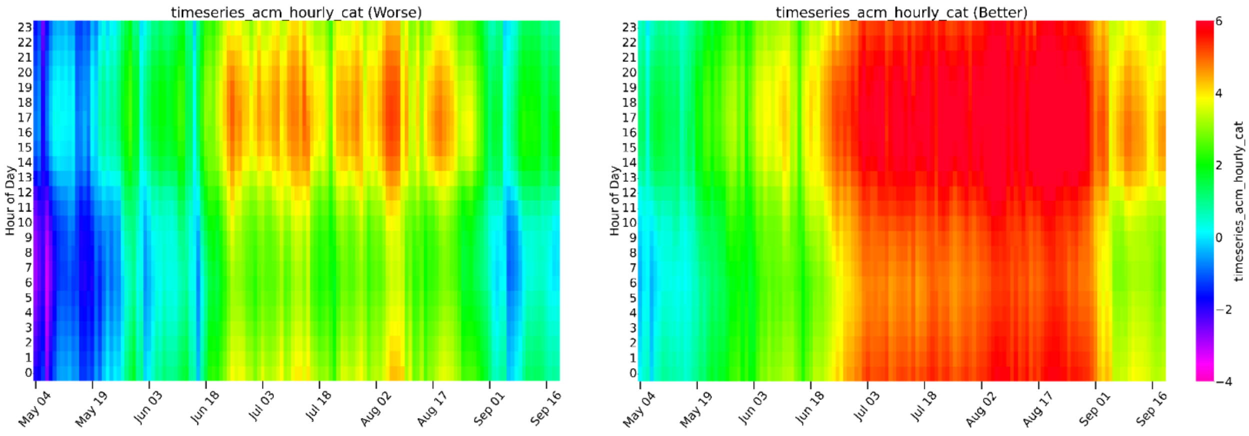
Figure 15: Adaptive comfort model category for Magisterparken A free running hours in (a) the less insulated case (worst for winter) and (b) the most insulated case (better for winter) – See the increased overheating risk in summer in the most insulated case (b).



(a) (b)

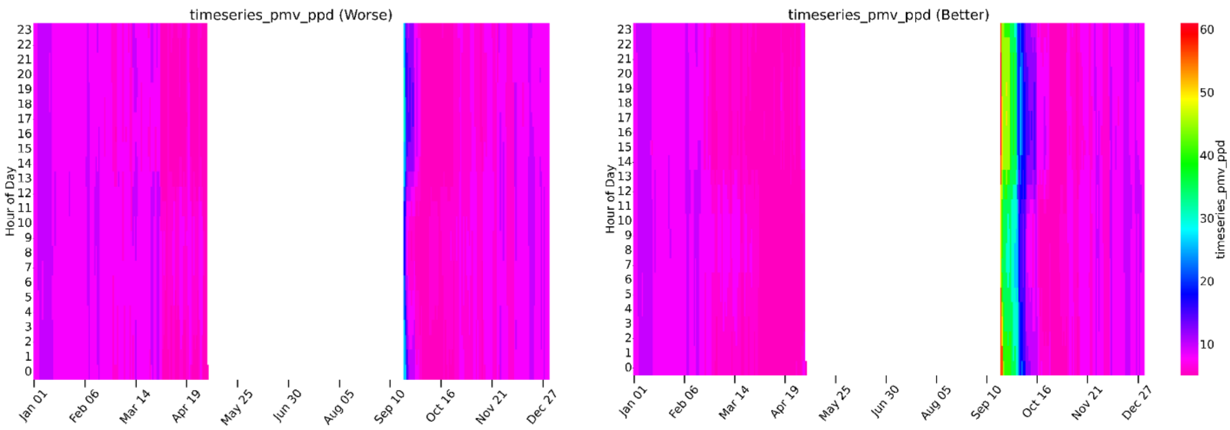
Figure 16: Adaptive comfort model points distribution in categories for Magisterparken A free running hours in (a) the less insulated case (worst for winter) and (b) the most insulated case (better for winter) – Also in this case the increase in the envelope insulation will lead to a reduction in winter energy needs, but an increase in summer overheating hours.

Another typology of plots that can be generated through the PREDYCE platform is carpet plots. Figure 17, Figure 18, and Figure 19 show the distribution for the whole run period of the indoor operative temperature, the PPD and the distances from the ACM central line. Carpet plots are generated for the two considered cases. By these graphs, it is possible to identify critical moments during the analysed period and verify over the whole simulation time the impact of a retrofitting scenario or of a single action variation on a given KPI. For example, when in summer, a free-running building is exploiting overheating to eventually plan additional design and operational counteractions.



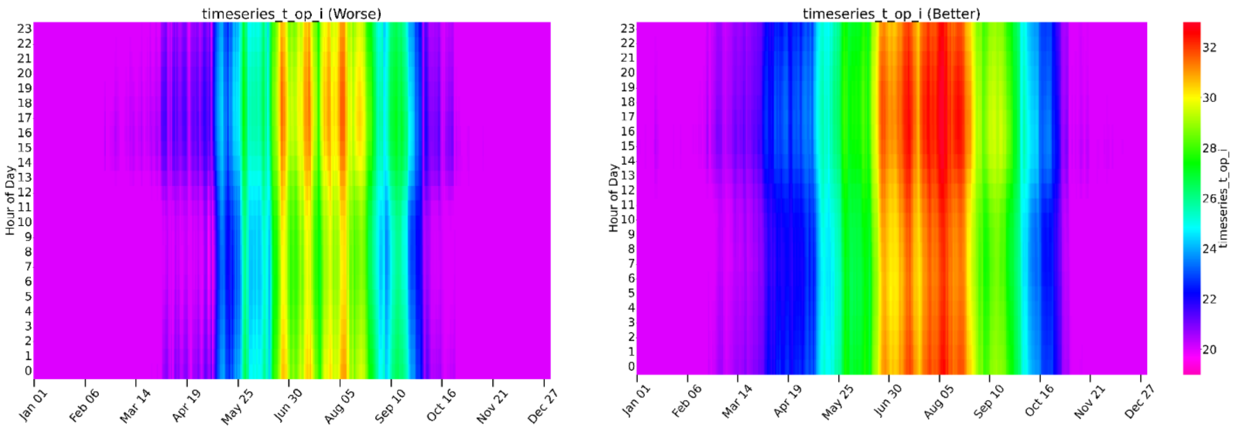
(a) (b)

Figure 17: ACM distance from central line carpet plots for Magisterparken A free running season in (a) the less insulated case and (b) the most insulated case



(a) (b)

Figure 18: PPD carpet plots for Magisterparken A heating season in (a) the less insulated case and (b) the most insulated case



(a) (b)

Figure 19: Indoor operative temperature carpet plots for a whole year in Magisterparken A in (a) the less insulated case and (b) the most insulated case

5 Conclusions and Outlook

The expert approach for setting up renovation roadmaps utilize the advantage of an expert inspecting the building and assessing which measures that can be applied to the actual building, considering available space, actual costs, necessary supplemental works, building tradition and regulations. This results in a very limited number of calculations needed, which in turn is a favour for the cost calculations that are not linear and therefore not directly applicable for an analytical approach.

However, the limited number of calculations in the expert approach cannot guarantee that the optimum solution is found in terms of the different KPI's used in the E-DYCE project. It is thus plausible that a better solution exists and that this better solution will be identified in the analytical approach.

Thanks to the scalability and the implement ability of the PREDYEC tool, it can be possible to efficiently run multiple simulations of a building EnergyPlus model by adding and varying retrofitting actions. Results may be retrieved at different levels, including the direct comparison of each run scenario and specific case time-series values, and to identify the statistical impact of each choice on selected KPIs via the production of heatmaps.

When applied to support retrofitting choices, one of the current limitations of the PREDYCE platform is the absence of cost-optimal analysis limiting results to energy and comfort indicators. Additionally, currently, the platform does not include optimisation algorithms, requiring running the whole set of simulations to identify better solutions further. Moreover, the initial IDF models must be generated respecting specific rules (mainly based on the selected type among alternative EnergyPlus objects) to automatically perform the PREDYCE actions for parametric analyses: e.g., windows should have spectral average values and not detailed ones for each wavelength.

However, with minor limitations, the complexity in model adaptation to be run via PREDYCE can be considered as already solved if considering models used in the EDYCE data flow since serious effort among all project partners has been put into achieving homogeneity in models' generation according to outputs detailed in the correlated tasks. Similarly, the PREDYCE support to retrofitting choices can be assumed as additional functionality that may be performed to IDF models already adapted to the other E-DYCE project platform functionalities e.g., the performance gap scenario launched via FUSIX and the calculation of DEPC KPIs.

The conclusion is thus that the analytical approach and the expert approach can go hand-in-hand and in that way provide the optimal solution. First the analytical approach can be used to identify a range of solutions that provide the optimum for selected KPI's and then the expert approach can be used to select among the optimal solutions in terms of costs and compliance with national building tradition and regulations.

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