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Review of the literature

about energy retrofit of schools

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Review by: *Nemanja Slankamenac*, 09/2021

The aim of this research is to figure out how GeoBIM can improve Asset Management. GeoBIM is the integration of BIM and GIS, which are representing indoor conditions and outdoor conditions respectively. The main problem is the complexity of BIM model in compareson to GIS one. The path of integration would be:

- Converting BIM model to IFC one
- Converting IFC file to spatial data format (a multi-patch shapefile)
  A multipatch feature is a GIS object that stores a collection of patches to represent the boundary of a 3D object as a single row in a database. Patches store texture, color, transparency, and geometric information representing parts of a feature.
- Integrating 3D spacial format and GIS data

Table 4
The geometry used for each of the four surveys.

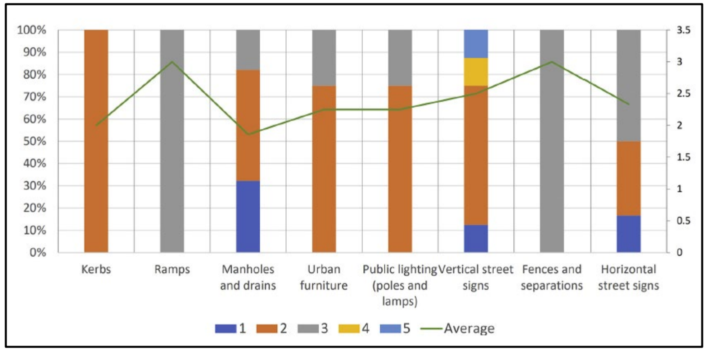
Survey	Geometry used to provide location information for the asset(s)
Indoor CA – Building	IfcSpace from BIM, converted to *rooms* within the spatial database
Outdoor CA - Building envelope & common parts	3D building, created by combining different elements from the BIM
Outdoor CA - Building's surroundings	Outdoor Private Space (GIS)
Outdoor CA - Public areas (neighbourhood)	Various individual features (GIS)

To ensure import data are maching breakdown for Condition Asessment, they are divided into groups:

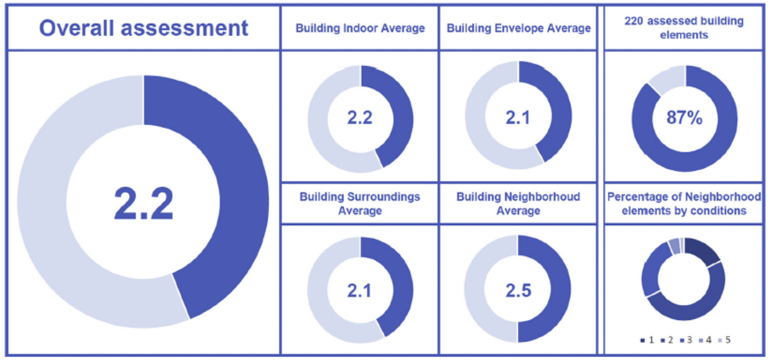
1. Features as windows, doors, stairs
2. Features needed to form the envelope (IFCSlab, IFCRoof, IFCWall etc.)
3. Benches, desks, chairs etc. are represented as simple points

Idea is also to implement condition assessment into BIM model, so firstly to rate the conditions as following example:

Results from outdoor analysis:



Overall results form CA:



Since GIS contains information about wider geographical range and BIM is concentrating on smaller portions, the idea is to implement BIM into GIS, so to form kind of twin city, which could be linked directly to smart city initiatives to ensure easier and faster general picture of the state as a whole, but also as individual building if needed.

Review by: *Nemanja Slankamenac*, 09/2021

The aim of this research is to figure out what is the energy consumption in the schools built in the different time periods since significance of schools in overall energy consumption is large.

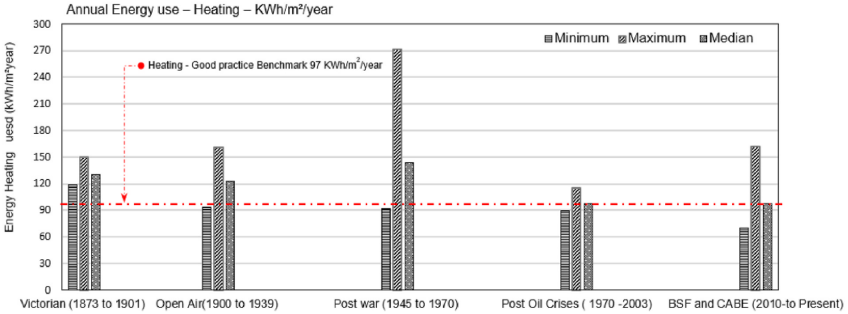
Four key performances were chosen to be analyzed and those are: electricity, heating, energy and performance rating according to the floor area.

The study has two stages:

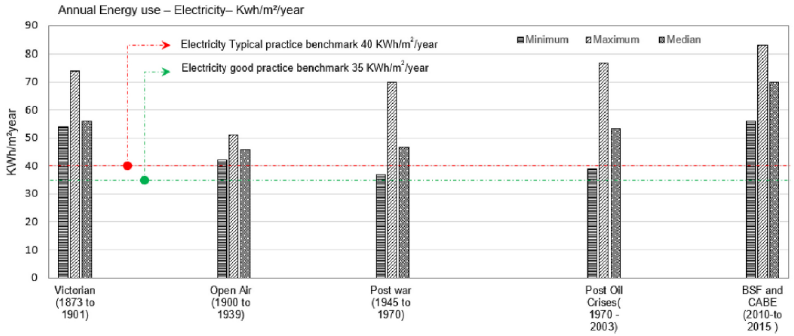
1. Dividing schools depending on the time period they were built in.
2. Exploring typical features the schools have depending on the time they were built. Those features are important from an energy efficiency point of view.

To compare properly these results, it's needed to show them taking into consideration the surface area.

Result 1:

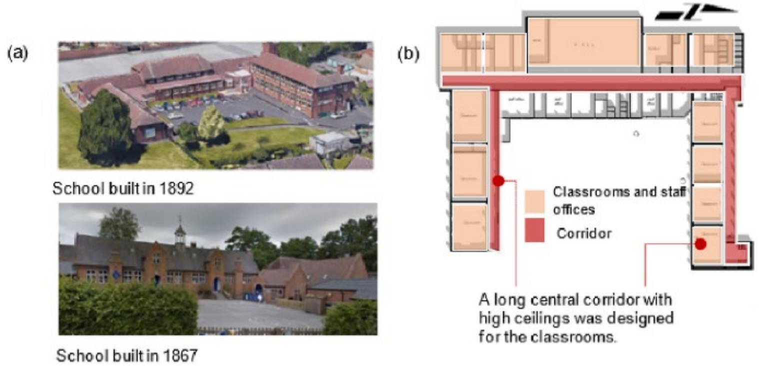


Result 2:



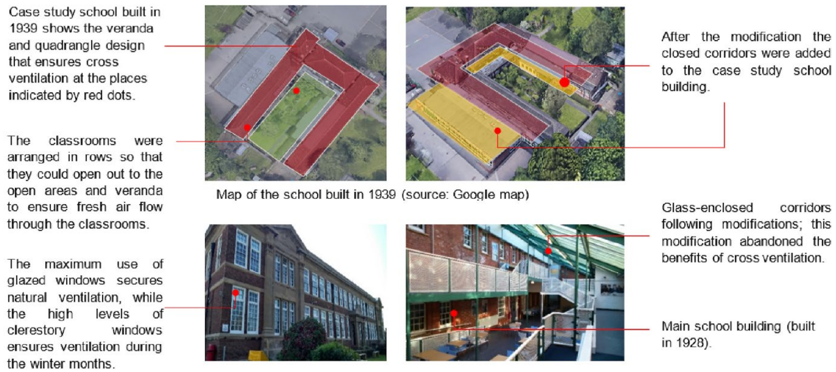
1) Victorian schools' buildings (1873–1901)

Schools built during this period are characterized by classrooms placed along hallways, large windows and high ceilings. Also, they are built using brick. All this leads to thermal comfort during summer and good iAQ. But the problem starts during wintertime when the losses are high. This is happening due to large single windows. Additionally, most of the classrooms are facing North, leading to lower sun gains. Moreover, their thermal mass is high, which results in stable indoor temperatures. However, schools built during this period are valuable historical heritage, so the renovation or any changes are not acceptable.



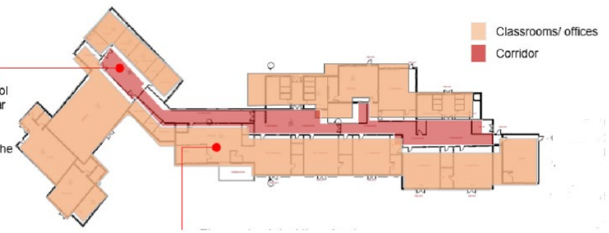
2) Open-air schools' buildings (1900-1939)

These buildings have problems due to the closing of the corridor which was used for the cross ventilation due to tuberculosis. Inefficiency happened especially during wintertime since the cross ventilation was always on, but at the same time heating system too, so the energy consumption was on a high level. Later on, windows for cross ventilation were closed due to the intention to improve performances during wintertime, but the result for summer became worse since cross ventilation which was assuring comfort was no longer possible.



3) Post-war schools' buildings (1945-1970)

Typical schools' buildings of this kind are characterized by prefabrication, lightweight construction and enlarged (usually single glazed) windows since the regulations required an increase of light level 2-5%. All this led to poor insulation, bigger losses and finally inefficient use of energy. Besides that, the problem of glare was present during wintertime. Discomfort in buildings like these is individual for every school since it depends on the orientation of the classrooms.
Usually the space was rearanged into cellular one, canceling the possibility of cross-ventilation, so improving the risk of overheating.



Case study school plan of a post-war school built between (1945–1970) drawn by the author).

4) Post-oil-crisis schools' buildings (1970-2000)

Since the problems that the previous schools' buildings have faced were realised, the new way of building schools was adopted, where the percentage of openings was reduced and instead the artificial lightning was adopted and also possibility for higher usage of mechanical ventilation. This lead to higher consumption of electricity. Also, sick building syndrome was a new problem arising due to absance of sufficient amount of natural ventilation.

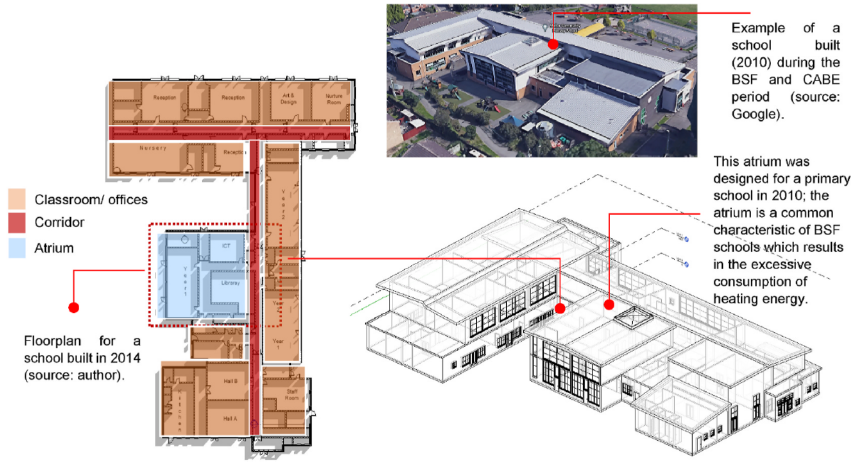
Besides this, infrared thermography is showing poor airtightness of the windows, since infiltration through the window frame was spotted.

(a) A classroom with a mechanical air conditioning system and mould on the ceiling due to a lack of ventilation

(b) The case study school built in 1972 showed a reduction in the glazed area. The presence of a veranda or opening windows allows the school to use air conditioning.

5) BSF and CABE schools (2010-present)

Due to all the problems that older built schools had, CABE had done the research in order to guide the further process of building schools. Although there was an effort to build schools with the acceptable environments, some schools failed to achieve that.
The assumption is that possible overheating is present due to a misunderstanding of the parameter of occupation.
Meanwhile, atriums are typically present in these schools. Even though they are assuring enough daylight and airflow, the problem of heat loss is increasing energy use.
Moreover, since the predictions are that the temperature will rise by 2°C in the near future, systems that are present in those buildings are not capable to regulate these changes.



Example of a school built (2010) during the BSF and CABE period (source: Google).

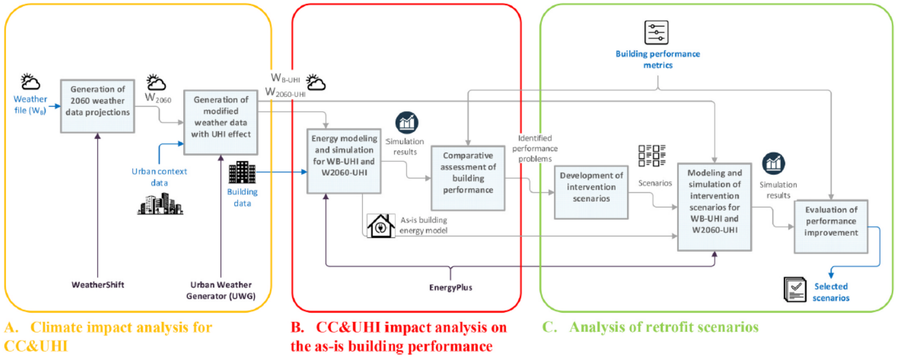
This atrium was designed for a primary school in 2010; the atrium is a common characteristic of BSF schools which results in the excessive consumption of heating energy.

Floorplan for a school built in 2014 (source: author).

Overall, the biggest problem lays in the question of how to find a balance between iAQ and thermal comfort, since we have seen that big single glazed windows and cross ventilation is preferable for summer months, but during winter time chillness is experienced. On the other hand, by reducing the natural ventilation and area of the windows, we are lowering energy consumption for the heating, but increasing the risk of overheating. Therefore, in the future, the relation between iAQ and thermal comfort should be examined and a good trade-off between the two of them should be found, as always in the process of engineering.

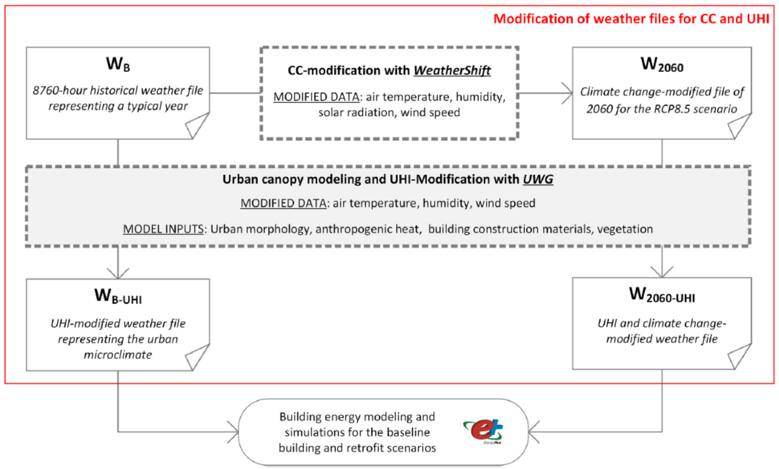
Review by: *Nemanja Slankamenac*, 09/2021

This study envolves a model of school in Turkey, following the analysis of weather, CC&UHI and retrofyt. It is divided into 3 main phases:



1. **<u>Climate impact analysis for CC&UHI:</u>**

   This analysis requires input of weather file and bringing the change in it in terms of future and UHI.



Hourly air temperature, humidity and wind speed data are modified, while the cloud cover cannot be considered until predictions are considered in predictive models.

From the weather file, after applying changes, three files are produced:

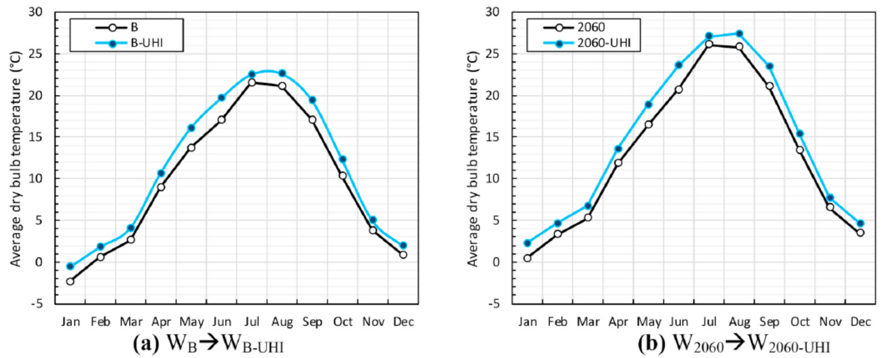
I. W_{2060}: W_B is modified for 2060 under the RCP8.5 emissions scenario with WeatherShift. This is an intermediary file generated to calculate $W_{2060-UHI}$

II. W_{B-UHI}: W_B is modified for UHI effects for the urban context with UWG

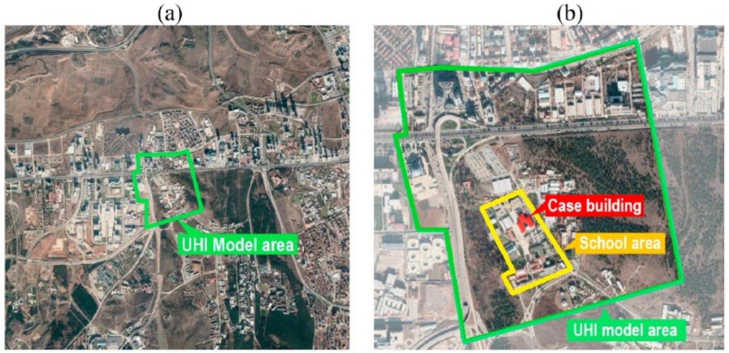
III. $W_{2060-UHI}$: W_{2060} file is modified for UHI effects for the urban context with UWG

Values that were analyzed are: dry-bulb temperature, Global Horizontal Radiation, Cooling Degree Days and Heating Degree Days.

Example:



2. **CC&UHI impact on the as-is building performance:**
This step includes energy modeling of the current state uf the building which is a complex process, since many details of the builing state needs to be inserted. It is very important that the model matches reality in as much percents as it is possible.
Simulation is done with both $W_{B\text{-}UHI}$ and $W_{2060\text{-}UHI}$ so to understand UHI impact on both current and future weather file.
Comparative analysis based on performance parameters is done after the simulation in order to realize which are the critical areas.



(c)

3. **Development and analysis of retrofit scenarios**

This scenario begins with spotting the weaknesses of the as-is situation and proposing scenarios that will lead to retrofit. Scenatios are usually decided based on weather heating or cooling is dominant. For every scenario, energy model is created separately and the analysis is done on both $W_{B\text{-}UHI}$ and $W_{2060\text{-}UHI}$ files.

Building performance indicators such as cooling, heating and total load are used and also heating and cooling densities per floor area. In this way, the results could be compared in decision made.
In therms of thermal comfort, adaptive one was used during this snalysis.

Interesting: Age is important parameter in thermal sensitivity.
Source: R. De Dear, J. Kim, C. Candido, M. Deuble, Adaptive thermal comfort in australian school classrooms, Build. Res. Inf. (2015)

Indoor overheating degree (IOD) is used to calculate the sensitivity of building to thermal stress.

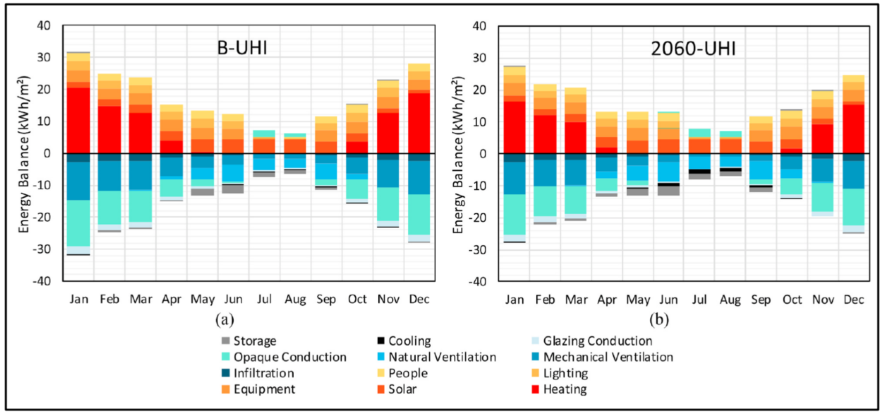
$$IOD = \frac{\sum_{i=1}^{N_{occ(z)}} \left[max\left\{ OT_{i,z} - T_{comf,i,z}, 0 \right\} \times t_{i,z} \right]}{\sum_{i=1}^{N_{occ(Z)}} t_{i,z}}$$

- Nocc(Z): total occupied hours of z in a given calculation period,
- t: time step (1 h),
- OTi,z: operative temperature at the time step i in the zone z.

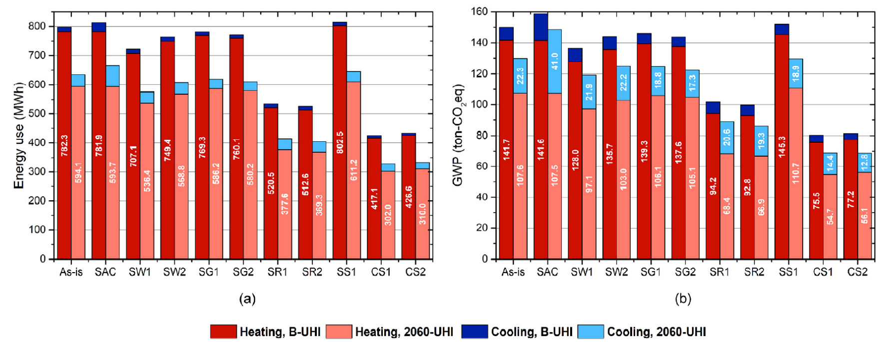
This table is showing possible scenarios in improvement of the as-is situation. Every peace of construction can have its own improvement and different technologies are included.
In the end combinations of scenarios are obtained.

Table 9
Scenario descriptions.

Scenario category	Building element	Label	Description	Details
Single	–	SAC	Installing air-conditioners to classrooms	Split-type air conditioners, COP = 3.80 Cooling setpoint = 25,5 °C Cooling period: May–October
	External wall	SW1	Additional thermal insulation	Table 6
		SW2	Utilizing AAC blocks	Table 6
	Roof	SR1	Additional thermal insulation	Table 6
		SR2	Installation of green roof	Tables 6 and 7
	Glazing	SG1 SG2	Replacing the glazing with a higher performing alternative	Table 8
	Sun-shading	SS1	Installing fixed sunshade outside the windows	Horizontal louvres on the southeast, and vertical louvres to on the southwest/ northeast windows. Louvres have slats with 0.8 m spacing and 0.8 m depth
Combined		CS1 CS2	SW1 + SG2 + SR1 CS1 + SS1	

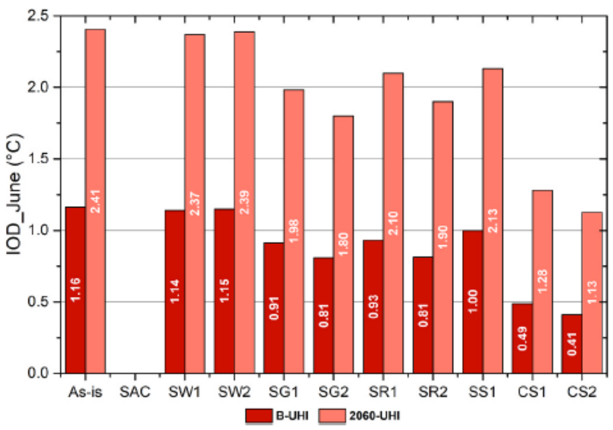


The graphs above are the summary of loads of as-is building. It shows the relation between gains and losses, where clearly can be seen that the future CC and raise of temperature is leading us to higher cooling load.



The graphs above are representing results of case scenarios in therms of energy use and Global Warming Potential. In this case the options could be easily compared.
In general, using only one scenario does not bring ang significant change, while by combining them, we can reach reasonable change in the system.

Indoor Overheating Degree (IOD) represents the sensitivity of the building to external stresses. It is preasent especially during summer, since the overheating is experianced. The most relevant month for analysis of IOD is June, since it’s the hottest when the school is used, so the reuslts are reported below both for current situation and for 2060 scenario:



It can be noticed that by implementing CC in weather file, IOD is cignificantly increased.

Review by: *Nemanja Slankamenac*, 09/2021

This paper is investigating the impact of strategies on typical schools placed in South, Central and North Italy.

In Italian schools heating takes 80-90% of energy use, while the cooling system is usually not installed because the schools are closed during summer.

Steps of the research:

1. Identification of parameters to be analyzed.
2. Defininf reference building.
3. Defining reference building variants taking into consideration passive strategies and Italian NZEB.
4. Results of energy peformance of reference building both before and after renovation.
5. Results of Indoor Environment Quality both before and after renovation.

Data used for chosen cities:

City	Climatic Zone	HDDs	Heating Season
Palermo	B	751	1 December–15 March
Rome	D	1415	1 November–15 April
Milan	E	2404	15 October–15 April

U-values for reference building and NZEB configuration for different cities:

Component	U (W/m² K)			
	Existing Configuration	NZEB Configurations		
		Palermo	Rome	Milan
External wall	1.70	0.39	0.30	0.28
Concrete and masonry roof	1.33	0.31	0.25	0.24
Concrete and masonry base floor	1.29	0.40	0.31	0.29
Windows	5.8	1.6	1.6	1.3

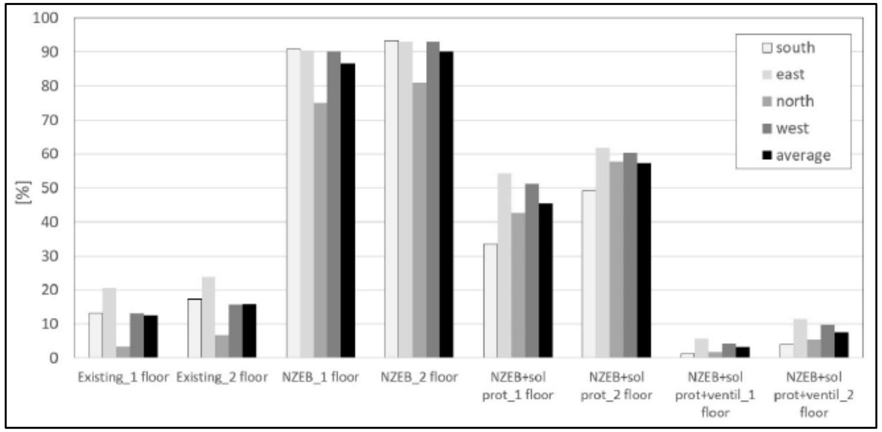
Strategies applies:

- Solar-protective devices
- Nighttime ventilative cooling
- Different window opening profiles

Relative savings from city to city are similar, raging grom 69% to 74%. Decreasing air changes from 1.4 to 0.3 leads to 25-28% of energy saving.

Interesting: The classroom oriented towards North is the coolest in reference building, while on the contrary for NZEB+shading South oriented classrooms are cooler. This phenomenon can be due to the rise of temperature in the unshaded corridor which has a common wall, so the transfer of energy occurs.

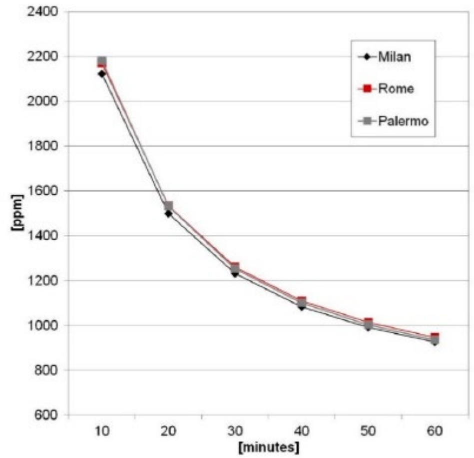
Discomfort hours using different building configurations in Milan:



In this case study, shading reduced discomfort hours to 51%.

Since the threshold of achieving iAQ is 1200ppm, it is obvious that the results are not satisfying.

To figure out how the natural ventilation would satisfy iQA, the simulation was done and the results are showed in a graph. Horizontal axis represents minutes per hour.



Solar shading and night ventilation reduces overheating risk in comparison to reference building, but the CO_2 concentration is not within the limits in both cases.

Using additional passive solutions like ground coupling ventilation should be taken into consideration after getting the results, but in this case, the economic parameters would be involved too.

Review by: *Nemanja Slankamenac*, 09/2021

The construction sector is responsible for 40% of final energy consumption and 36% of greenhouse gas emissions in Europe.

The energy consumption in schools is mostly related to heating and lighting.

Two main assessments:

1. Environmental analysis linked to energy consumption and greenhouse emossions
2. Economic analysis

The case study building was built in the 1960s with exposed steel construction and opaque infill panels. It is equipped with natural gas boiler heating system and radiators and no cooling system was implemented.

Glazing surface was a significant part of this building and it was characterized by an iron frame with 4mm single glass, so the windows considered for retrofit are:

1. Type 1 window, U-value 2.83 W/m2K, g-value 0.755 and T-vis 0.817
2. Type 2 window, U-value 2.54 W/m2K, g-value 0.440 and T-vis 0.472

Regarding walls, thermal insulation was proposed as following table shows:

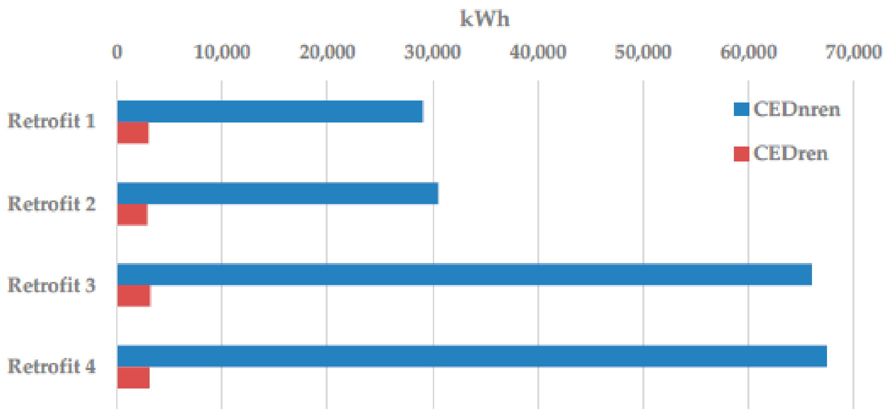
External Insulation	Density	Thickness (cm)
Insulation glue	1500 kg/m^3	0.5
XPS	32 kg/m^3	5
First leveling plaster	2000 kg/m^3	1
Fiberglass mesh 33 × 33	1 kg/m^2	~0
Second leveling plaster	2000 kg/m^3	1
Insulation glue	1500 kg/m^3	0.5

By inserting insulation transmittance of external walls is dropping down from 0.214 W/m2K to 0.188 W/m2K.

By combining retrofit proposals there are four scenarios:

- Retrofit 1, replacement of transparent surfaces with Type 1 windows
- Retrofit 2, replacement of transparent surfaces with Type 2 windows
- Retrofit 3, the same as Retrofit 1 plus a thermal coat with a thickness of 5cm
- Retrofit 4, the same as Retrofit 2 plus a thermal coat with a thickness of 5cm

The most favorable retrofit scenario from annual heating energy consumption are Retrofits 1 and 2 and this is due to the fact that a big part of the building envelope, in this case, is glazing.



As it can be seen, the retrofit solutions are bringing just non renewable primary energy to the building.

Results concerning CO2 payback:

Retrofit Option	ΔEE (kWh)	ΔEC ($kgCO_2eq$)	Energy Saving (kWh/y)	Avoided Emissions ($kgCO_2/y$)	EPBT (Years)	CPBT (Years)
Retrofit 1	32,124	8231	14,731	2961	2.18	2.78
Retrofit 2	33,472	8827	12,891	2591	2.60	3.41
Retrofit 3	69,217	16,651	15,054	3026	4.60	5.50
Retrofit 4	70,565	17,247	13,184	2650	5.35	6.51

EPBT- Energy Pay-Back Time CPBT- CO2 Pay-Back Time

The various retrofits cause an increase in the embodied impacts which is only temporary, since the obtained energy and carbon paybacks are shorter than the useful life of the components.

Net Present Value of retrofit interventions (euros):

Cash Flows and NPV	Retrofit 1	Retrofit 2	Retrofit 3	Retrofit 4
Present value (energy savings)	36,270.62	31,427.93	36,226.61	31,468.96
Present value (tax deduction)	20,094.95	22,007.58	34,252.11	36,164.74
Lump-sum investment	51,835.81	56,769.52	88,354.81	93,288.52
NPV	4529.76	−3334.01	−17,876.09	−25,654.83

The only retrofit that gives economic benefits is the first one with a positive NPV.

This case study should not be generalized, since it concerns a school built in the characteristic age (style), so particular strategies, such as replacing windows, are relevant. For some other schools, maybe some other strategies would be more appropreate.

Review by: *Nemanja Slankamenac*, 09/2021

The work focuses on the school and has 3 aims:

1. Investigating thermal environment of the school during summer
2. Evaluate overheating regarding the threshold for children's comfort
3. Introducing retrofit measurements and „soft“ solutions to the problems

The considered school was built in 2013. and students from 4 to 11 years old are attendants. Manual opening of the windows is used to naturally ventilate classrooms.

U-values of school elements according to UK Building Regulations:

Element	U-value [W/(m².K)]
External walls	0.35
Roof	0.25
Party walls	0.20
Windows/doors	2.2
Floors/ceilings	0.25
High usage entrance doors	3.5

Ventilation profiles were collected by interviewing building managers and window mounted accelerometers and they are summarised in the following table:

Number of Open Windows	Open Window Area (m²)	Opening Threshold (°C)	Closing Threshold (°C)
1	0.78	22	18
2	1.56	25	18
3	2.34	27	18
4	3.12	30	18

Results of the study are showing that 64% of classrooms had a risk of overheating.

„Night Purge“ strategy was a useful strategies in mitigating overheating risk.

Temperatures in classrooms during occupation hours in summer:

	Classrooms										
	1	2	3	4	5	6	7	8	9	10	11
Orientation	East	East	East	West	West	East	East	East	East	West	West
Average	23.0	23.4	23.8	24.4	23.6	23.9	23.5	23.6	23.0	24.0	23.8
St dev	1.1	1.0	0.8	1.0	1.4	0.9	1.4	1.5	1.6	1.3	1.5
Max	27.6	28.3	28.0	28.8	29.5	27.9	29.1	30.5	29.4	29.0	28.8
Min	19.8	20.4	21.1	20.7	19.2	20.1	18.7	17.5	17.8	20.4	20.0

It has been recognized that despite an external night temperature decrease by 7°C, the majority of classrooms do not experience a decrease larger than 2°C.

Another noticeable fact is that there is no time lag between solar irradiance and internal temperatures. This is because of the low thermal mass of the building and the usage of blinds.

Since the installation of an external louver as a retrofit scenario would have a high initial cost, firstly the analysis considered „soft“ interventions such as closing the windows and closing window blinds if the temperature exceeds 25°C by notifying teachers or installing low emissivity coating on windows. Anyhow, in order to maintain required air changes per hour, minimum window opening was introduced.

In the following table, the results are reported concerning „hard“ and „soft“ interventions.

Category	*Crit. 1*[α]	*Crit. 2*[β]	*Crit. 3*[γ]	*$TM52_{ad}$ result*
Monitored Internal	13.6%	11	0	Fail
Simulated Internal	14.2%	17	1	Fail
External Shading	7.0%	8	1	Fail
Emissivity	7.9%	8	1	Fail
Informed Ventilation	10.5%	11	1	Fail
Night Purge	0.8%	1	0	Pass

[α] % Occupied hours, [β] hours of exceedance, [γ] 1(True):exceeds upper threshold)

The threshold for Criterion 1 is 3% of occupied hours. Under TM52 the two or more failed Criteria are resulting as failure. In this case, only the „Night Purge“ can solve the overnight heating.

In the end, as the goal was to find out of the „soft“ measures could help in solving the overheating, it has been given that „Night Purge“ could play important role in controlling this phenomenon. However, a solution like this will need to bring some changes in general everyday practice at school, but it still has strong advantage from the economic point of view.

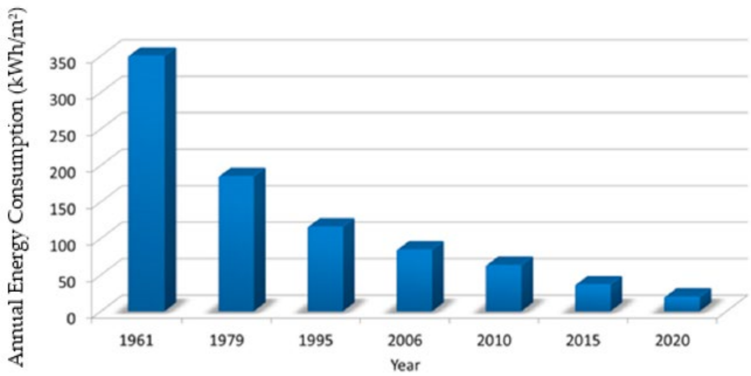
Review by: *Nemanja Slankamenac*, 09/2021

This research is based on three schools that were havily retrofitted in Denmark.

A big problem when it comes to retrofit analysis is that often the real results we got and the ones calculater are considerably different. This performance gap could be related to things like:

1. Limitations and uncertanties of building energy models
2. Mismatch between design and as-built building quality
3. Changes and modifications throughout the design and construction phase
4. Occupants and building user behavior and pattern

There were changes in Danish regulations and the figure below represents the maximum allowed yearly pripary energy consumption for 150m2 residential building.



Common strategies are adding around 10cm of exterior insulation, changing windows and adding a heat recovery unit to the ventilation system. Implementing those changes, up to 70% savings were reported.

- School A consists of 16 blocks, where part of the blocks were built in 1954, 1967 and 1974. The oldest ones experienced the biggest upgrade.
- School B consists of 12 building blocks mainly built in 1954 and later on in 1990.
- School C cincists of 11 blocks, The first part was built in 1961 and a small part later in 1971 and 1996.

When doing a compareson like this, it is important to indicate and organize information about the buildings' use, physical envelope construction, energy system design and so on, which can be represented like the table below:

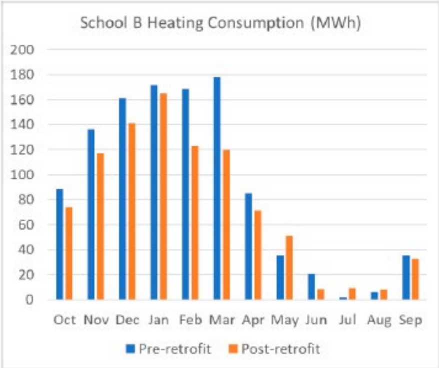
	School A	School B	School C
Indoor Floor Area	11,900 m^2	8700 m^2	8900 m^2
Construction Date	1954	1953	1961
Number of Blocks	16 buildings	12 buildings	11 buildings
Number of Students	677 (2018)	536 (2018)	507 (2018)
Number of Teachers	31 (2018)	27 (2018)	28 (2018)
Operation Hours	6:30–19:00	6:30–19:00	6:30–19:00
Exterior Walls	300 mm brick/100 mm wood along with 75–150 mm mineral wool insulation. 120 mm lightweight concrete/in the teachers' residence is equipped with 50 mm insulation. Basement walls are made of 350 mm light concrete.	Original exterior walls from 1953 are built with massive 480 mm thickness bricks with an overall U-value of 1 $W/m^2 \cdot K$. Hollow walls at SFO are of 300 mm brick and 75 mm insulation of 0.42 $W/m^2 \cdot K$ U-value.	240–350 mm Brick with 125–150 mm insulation in 9 blocks. In the two newer building blocks, 150 mm lightweight concrete is implemented with 200–250 mm mineral wool insulation.
Roofs and Ceiling	Roof tiles, unheated roof space. In the four blocks built in 1954, the ceiling is composed of 120–170 mm brick with 75 mm mineral wool insulation. In the newer blocks, 200–250 mm brick is used with around 150–200 mm mineral wool insulation.	Roof tiles with unheated roof space. Roof is mainly 200–250 mm brick with 170 mm insulation with 0.2 $W/m^2 \cdot K$ U-value. Flat roofs have 100 mm insulation with U-value of 0.36 $W/m^2 \cdot K$, where roof in the SFO has 200 mm insulation.	A flat roof made up of 200–250 mm brick with 50–150 mm mineral wool insulation in nine blocks. The two new blocks built in 1971 and 1996, the brick walls are equipped with 200–220 mm mineral wool insulation.
Floors	100–150 mm concrete with 50 mm lightweight expanded clay aggregate/100 mm mineral wool insulation	150 mm uninsulated concrete and 50 mm lightweight expanded clay aggregate in the basement	150 mm concrete with 50–100 mm mineral wool insulation
Windows and Doors	Mainly double-glazed windows and doors of U-value ranging between two and 3 $W/m^2 \cdot K$, with single-glazed windows in the four blocks built in 1954	The school windows were retrofitted in the early 2000's to double-glazed windows of U-value ranging from 2.2 to 3.1 $W/m^2 \cdot K$ with single-glazed windows and doors in two blocks built in 1953. The basement has single-glazed windows of 4.9 $W/m^2 \cdot K$ U-value.	Double-glazed windows of U-value in the region of 2.8 $W/m^2 \cdot K$ and doors with many single-glazed components in all blocks
Heating System	Direct district heating loop with multiple water circulation pumps and radiator/s in each room	Direct district heating loop with multiple water circulation pumps and radiator/s in each room	Direct district heating loop with multiple water circulation pumps and radiator/s in each room
Domestic Hot Water	Centralized production in a storage buffer tank	Centralized production using APV heat exchangers in a 400-L storage tank with 70 mm mineral wool insulation	Centralized production in two storage tanks of 300 and 1500-L storage with 100 mm mineral wool insulation
Heating Manage-ment	Central heating control with heating setpoint in each building block	Central heating control with heating setpoint in each building block	Central heating control with thermostatic valves in some blocks
Ventilation	Mainly mechanical ventilation systems (ranges between 1200 and 10,000 m^3/h nominal air flow) with natural ventilation in one block and heat recovery units	A mix between mechanical ventilation systems and natural ventilation in the majority of blocks with heat recovery units	All blocks have mechanical ventilation systems (ranges between 700 and 6000 m^3/h nominal air flow in different blocks) with heat recovery units
Lighting	A mix of T5 and T8 light tubes with motion sensors in specific zones	A mix of one and three lines T5 light tubes with motion sensors in some classrooms	A mix of T5 and T8 light tubes with motion sensors in bathrooms, and technical rooms

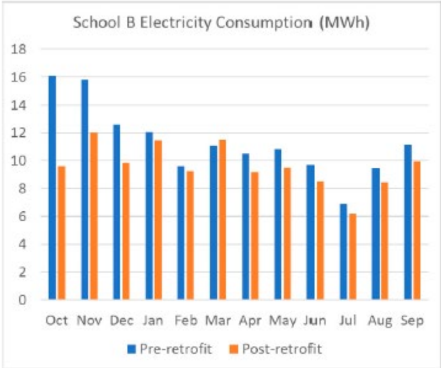
Following the retrofit strategies, changes that were made in every school were pretty similar and are:

- upgrading the light,
- insulating interior layer of the attic space,
- insulatin interior side of exterior wall,
- upgrading skylights,
- replacing domestig water circulation pumps and
- insulating pipes, valves and pumps in all technical rooms.

Post-evaluation considering one year operation period after completion of the retrofits was carried out and moreover, the focus was on heating and electricity consumption.

In the figure below, the comparative charts for school B can be found:





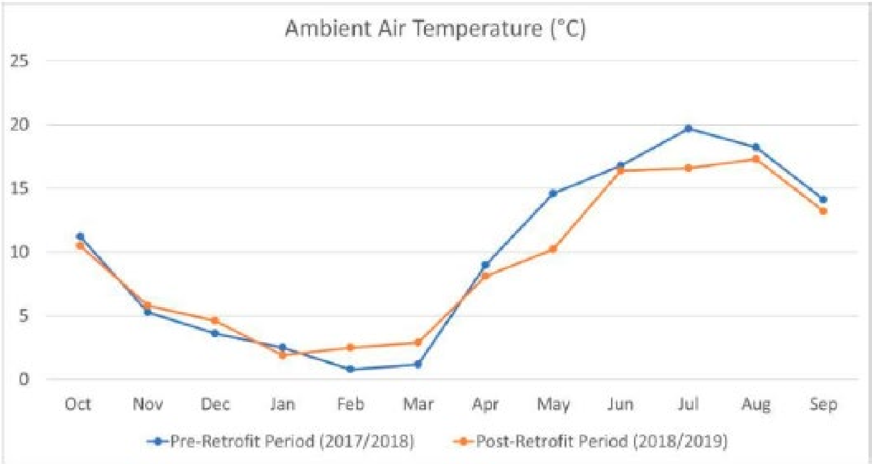
Even though some months experienced reduction in heating energy saving, some months experienced higher consumption after the rerofit, like May in the case of school B. This id due to different weather conditions in the pre-retrofit and post-retrofit year.

The summation of analyzed paramters can be found in the table below:

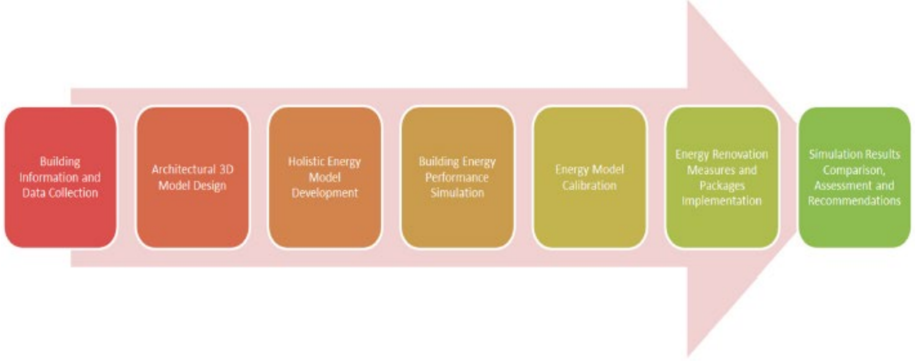
	School A	School B	School C
Pre-retrofit annual heating consumption (MWh)	1383	1088	983
Post-retrofit annual heating consumption (MWh)	1167	920	892
Annual Heating Savings (%)	15.7	15.4	9.3
Pre-retrofit annual electricity consumption (MWh)	240	136	165
Post-retrofit annual electricity consumption (MWh)	235	115	143
Annual Electricity Savings (%)	2.2	15.0	13.2

Months like February and March in post-retrofit period are warmer than the ones before. This is not only due to retrofit savings, but also because of the warmer weather. For example, ambient air temperature in May after retrofit is lowerd by 5°C.

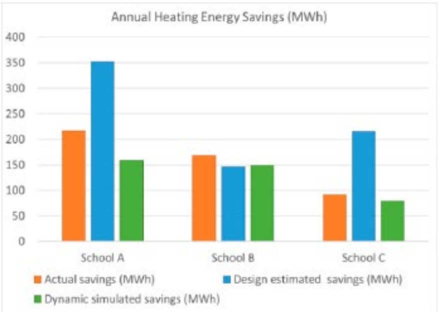
Average monthly ambient air temperature for whole year is represented in the graph below:

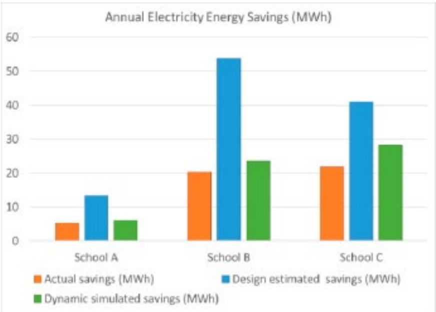


The path of energy modelling and simulations in this case is as follows:



After the modelling and the analysis, it has been shown that dynamic simulations more accurately predict the results in terms of electricity consumption savings in compareson to design estimations. Visualization can be found below:





There is lack of willingness to ensure that the savings are attained during post-retrofit phase. As it can be seen from the analysis shown previously, average performance gap between the expected and real numbers are 61% for annual heating and 136% for enectricity savings. On the other hand, using dynamic energy performance model, the performance gap was 16-29% for electriciy and 11-26% for heating consumption.

In conclusion, based on the results, dynamic model aproach allows to lower performance gap between expectations and reality when compared to tabulated static approach, which leads to innacurate results with a large margin of errors.

Review by: *Nemanja Slankamenac*, 09/2021

Energy-efficient buildings require a new set of „green“ skills for design, construction and post-completion stages.

In general, there is a division when it comes to skills:

1. „generic“- those are not specific to a particular subject and can cover a wide area of diverse skills. Example: numerical skills, professional communication skills, problem-solving skills, computer skills, etc.
2. „specialist“- linked to individuals who are skilled in a specific field. Those could be split into „new“ and „existing“ skills, where „new“ are related to and „up-skilling“ and use of advanced equipment and „existing“ are related to ones that individual/workforce already possesses.

Green skills could be linked to the process of adopting new technologies within buildings and those skills will evolve with the introduction if new technologies.

Low carbon skills are referring to focus on design stages and lifecycle in general.

Mainly these skills are the ones to be adopted by the construction sector through „up-skilling“ or „re-skilling“.

Concerning retrofit energy-efficient buildings, they demand cooperation with the government, supply chain and training bodies in order to gain necessary skills and knowledge.

The Energy Efficiency Measures (EEMs) are the initial methods to reduce energy consumption and they should be adopted prior to the use of more complex technologies.

There are key actors that must be aware of technologies and skills that are involved in retrofit projects, and those are the Local Authorities (LA) energy team, EEM contractors and School end-users.

Tables 2 and 3 are providing key actors’ interests and required skills definition for every key actor that was mentioned above.

Review by: *Nemanja Slankamenac*, 09/2021

This study has an aim to compare the calculated and real savings of retrofitted buildings. The buildings are located in Poland.

- Group A: Two schools with additional thermal insulation, modernization of central heating system and hydronic balancing.
- Group B: Two schools with additional insulation.

Basic information regarding schools:

Building	Year of construction/year	Area/m^2	Number of pupils	Number of staff
A1	1956	2903	463	73
A2	1978	3658	565	75
B1	1957	2162	386	60
B2	1910	1028	60	17

External walls are built in the traditional way, of hollow brick and there is natural ventilation in individual rooms where the air is supplied provided by hygrostered window diffusers.

Performed operations:

- Building A: external wall insulation, wall insulation at the ground, insulation of the roof and replacement of central heating installation.
- Building B: external wall insulation, wall insulation at the ground and insulation of the roof.

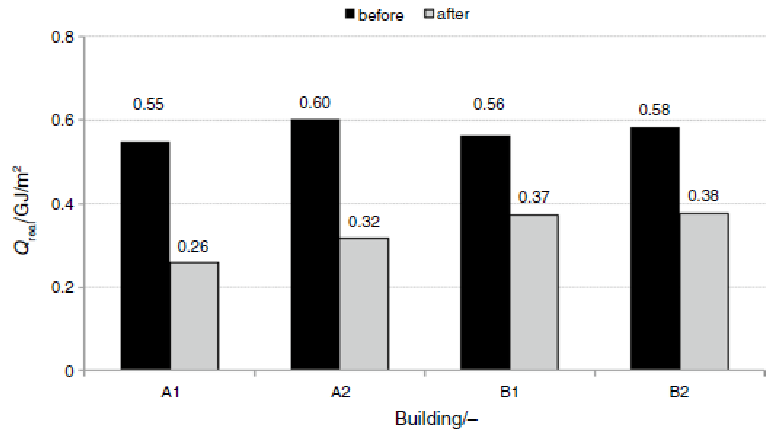
In buildings A, due to the replacement of the central heating system increasing efficiency has been achieved.

Characteristics of buildings before and after applying retrofit solutions:

Building	$U_{external\ wall}$/$Wm^{-2}K^{-1}$		U_{roof}/$Wm^{-2}K^{-1}$		Design thermal load/kW		Useful energy/final energy consumption for heating/GJ per heating season	
	Before	After	Before	After	Before	After	Before	After
A1	1.05	0.24	1.67	0.22	270	157	1711/2555	786/908
A2	1.14	0.24	0.58	0.22	332	222	1786/2667	936/1081
B1	1.38	0.24	1.68	0.22	235	129	1331/1638	482/593
B2	1.09	0.24	1.45	0.22	114	60	694/818	279/329

Retrofit solutions decreased U value of exterior wall and foor, which lead to decrease in design thermal load.

After applying retrofit solutions for schools, results for heating energy use are reported below:



The difference between Group A and Group B is noticable due to the fact that no hydronic balancing of modernized heating installation was carried out in schools from Group B.

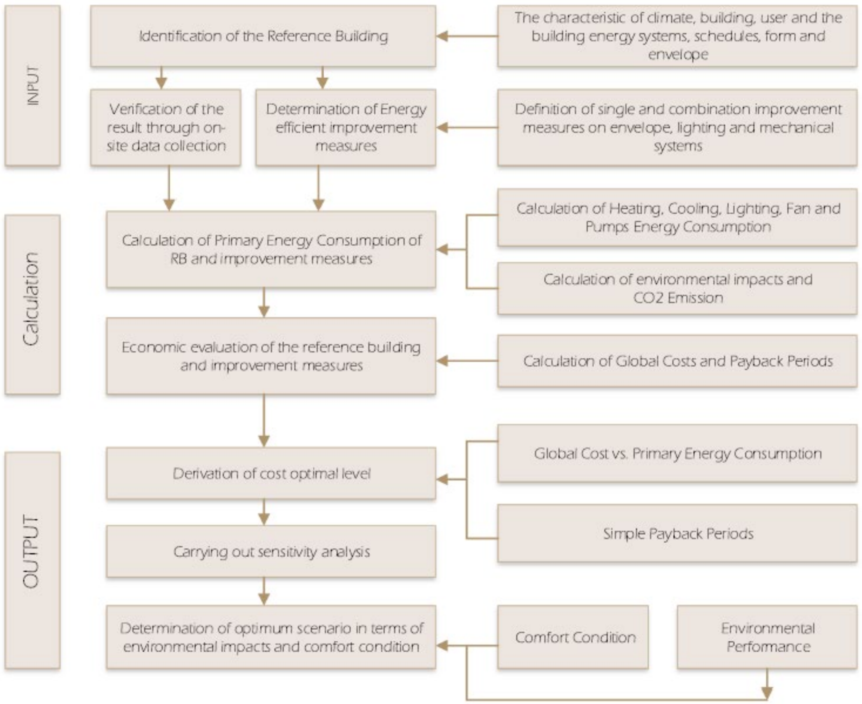
In conclusion, after thermal insulation of external walls, hydraulic balancing of heating system is needed in order to adapt the system to a new configuration and prevent overheating.

Review by: *Nemanja Slankamenac*, 09/2021

While computing retrofit scenarios and calculating their effect, there are many parameters to be taken into account when making the decision. One parameter is also the budget of the school.

With that said, building a reference model of the school and taking step by step procedure will lead us to results in terms of important parameters like Primary Energy Ratio or Payback Period, throughout which the discussion about scenarios can start.

Steps that were taken in this case study:



Two locations in Turkey were chosen as they represent two different climatic zones. The first one is Istanbul and the second one is Erzurum. Climatic characteristics for each city are reported below.

	Average yearly Temperature (°C)	Average yearly Humidity (%)	Average Solar Radiation (kWh/m²a)	Average Monthly Temperature range (°C)	Average Monthly Humidity range (%)	Solar radiation range (kWh/m²)	Climate Type
Istanbul	14	76	1400	3–27	40–94	1.80–6.73	Moderate
Erzurum	6	65	1600	−16–28	20–85	1.48–6.83	Cold

Since most of the schools in Turkey were built before 2000. thermal insulation in external walls is assumed as not present. There is no mechanical ventilation.

Typical schools i Turkey are represented in the pictures below.


Gaziosmanpaşa Province, Yeni District, Primary School

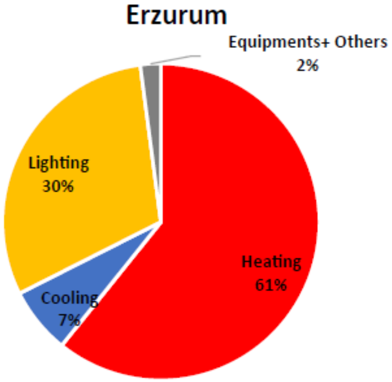

Sancaktepe Province, Sefa Yenidogan District, Safa Primary School

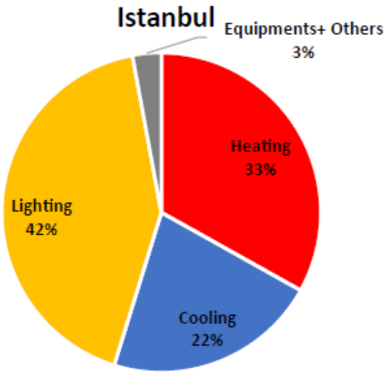

Sultanbeyli Province, Hamidiye District, Mimar Sinan Primary School

Physical properties of Reference Building were adopted after defining characteristics of typical schools in Turkey.

Location	Istanbul and Erzurum
Orientation	315o (CW normal angle of North facade)
Environment	Open land, without any shading element and structure in the nearby environment
Floor area (m^2)	1541
Total floor area (m^2)	7705
Floor height (m)	3.30
Facade surface area (m^2)	3570.50
Roof area (m^2)	1852.45
Glazing area (m^2)	660.50
Glazing ratio (%)	20
Number of floors	5 (basement + ground + 3 typical floors)

The results obtained concerning Primery Energy Consumption are reported below.





Going further to the retrofit actions, they are divided into 3 main cathegories:

1. Envelope (E): improvements in insulation level of the opaque systems (O) and the glazing systems (GL);
2. Lighting (L): actions to manage the interior lighting's energy consumption;
3. HVAC (H): enhancements to increase the efficiency of the HVAC systems.

And for every cathegory there are few possible improvements listen in the teble below.

O1	The first level of whole opaque system improvements, insulation level based on TS825-2013;
O2	The second tier of whole opaque system improvements, insulation level about 25% higher than TS825-2013;
O3	The third level of overall opaque system enhancements, insulation level approximately 50% greater than TS825-2013;
GL1	The first level of glazing improvement: Double Glass, U = 1.8 $W/m^2{}^\circ K$, Tvis = 0.79, SHGC = 0.70 (Equal to TS825-2013 level);
GL2	The second level of glazing improvement: Double Glass, U = 1.5 $W/m^2{}^\circ K$, Tvis = 0.74, SHGC = 0.56;
GL3	The third level of glazing improvement: Triple Glass, low-e, U = 1.1 $W/m^2{}^\circ K$, Tvis = 0.67, SHGC = 0.52.
L1	70% Fluorescent, 30% Incandescent (BEP-Tr level);
L2	100% Fluorescent;
L3	Lighting Control.
H1	High-Efficiency Non-Condensing Boiler (Nominal Capacity = 0.88 COP);
H2	Condensing Boiler (Nominal Capacity = 0.95 COP);
H3	Chiller 2.5 COP;
H4	Chiller 4.0 COP;
H5	Radiant Heating Floor;
H6	Radiant Heating and Cooling Floor.

Since the costs are the important parameter of retrofit actions, after consultations with school managers the initial investment costs were defined, and throughout them retrofit packages too, which are reported in the table below.

	Envelope Measures		Lighting Measures		HVAC measures		
Package	Thermal Insulation	Glazing Systems	Lamp Types	Lighting Control	Boiler	Chiller	Radiant Floor
P1	O1	GL1	L1	L3	–	–	–
P2	O1	GL2	L2	L3	–	–	–
P3	O1	GL3	L2	–	–	–	–
P4	O2	GL1	L1	–	–	–	–
P5	O2	GL2	L2	L3	–	–	–
P6	O2	GL3	L2	–	–	–	–
P7	O3	GL1	L2	L3	–	–	–
P8	O3	GL2	L1	–	–	–	–
P9	O3	GL3	L1	L3	–	–	–
P10	–	GL2	–	–	H1	H3	–
P11	–	GL3	–	–	H2	H4	–
P12	O1	GL2	L1	L3	H2	H4	–
P13	O1	GL3	L2	L3	–	–	H6
P14	O1	GL2	–	–	H2	H4	H6
P15	O1	–	–	–	H1	H3	–
P16	O1	GL3	L2	L3	H2	H4	H6
P17	O2	GL3	L1	–	H2	H4	–
P18	O2	–	L2	–	–	–	H6
P19	O2	GL3	–	–	H1	H3	H5
P20	O2	–	L1	L3	H2	H4	H6
P21	O3	GL2	L2	L3	H2	H4	–
P22	O3	GL3	–	–	H1	H3	H5
P23	O3	GL2	–	–	H2	H4	–
P24	O3	GL2	L2	L3	–	–	H6
P25	O3	–	L2	–	H2	H4	H5
P26	–	–	L1	L3	H2	H4	H6
P27	–	–	–	L3	H1	H3	–
P28	–	–	L1	–	–	–	H6
P29	–	–	L2	L3	H2	–	H6
P30	–	–	L2	L3	–	H3	–
P31	–	–	L2	–	H2	–	–

Besides these performances, Global Cost was calculated as summation of:

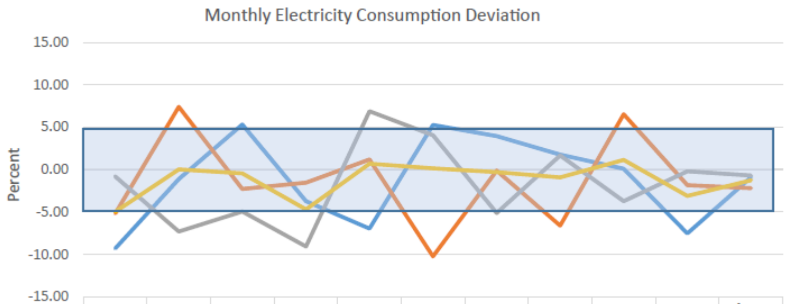
- Initial investment cost
- Running cost
- Energy cost
- Replacement cost
- Disposal cost

The inflation rate and discount rate were taken according to the Central Bank of Turkey.

Primary energy consumption was calculated for every single improvement and if any individual measure increases the amount of case buildings' PEC, it should be excluded from further analysis.

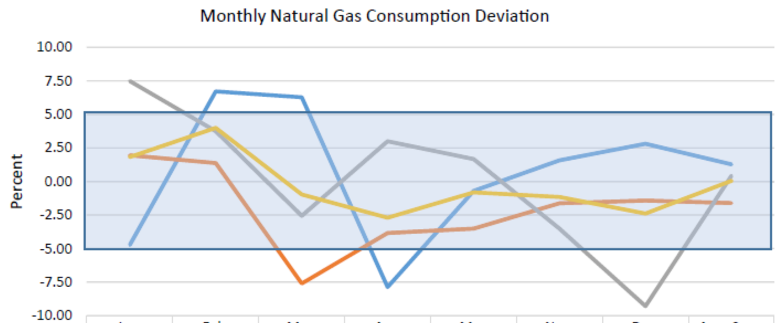
After completing a model, results from the simulation were compared to the real ones measured in three schools.

The resulting deviations between simulation and real values for electricity consumption are reported in the figure below.



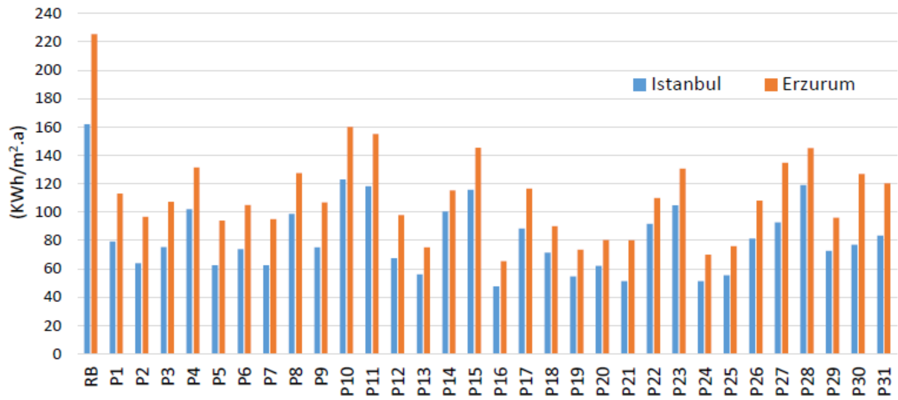
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Sep.	Oct.	Nov.	Dec.	Ann. Sum
School1	-9.29	-1.11	5.30	-3.73	-6.95	5.26	3.96	1.77	0.10	-7.53	-0.92
School2	-5.15	7.41	-2.28	-1.55	1.19	-10.22	-0.12	-6.61	6.54	-1.83	-2.18
School3	-0.81	-7.30	-4.93	-9.05	6.89	4.04	-5.12	1.67	-3.73	-0.20	-0.71
Average	-4.97	0.03	-0.44	-4.68	0.70	0.16	-0.29	-0.91	1.15	-3.09	-1.27

The resulting deviations between simulation and real values for natural energy consumption are reported in the figure below.

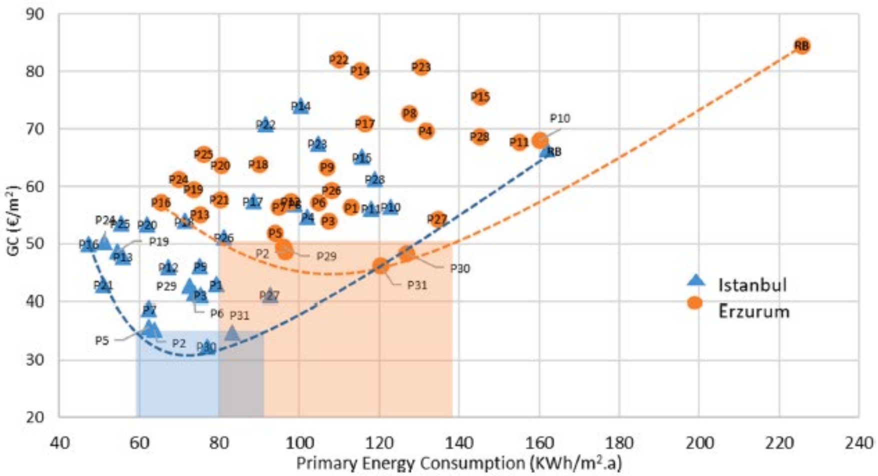


	Jan.	Feb.	Mar.	Apr.	May	Nov.	Dec.	Ann. Sum
School1	-4.71	6.72	6.28	-7.87	-0.70	1.57	2.82	1.29
School2	1.96	1.38	-7.61	-3.84	-3.52	-1.63	-1.42	-1.60
School3	7.49	3.75	-2.56	3.01	1.67	-3.52	-9.29	0.42
Average	1.83	4.00	-0.97	-2.70	-0.81	-1.15	-2.39	0.05

After the simulation of retrofit packages, the values concerning PEC (Primary Energy Consumption) were represented on the chart below both for Istanbul and Erzurum.



The charts were obtained for Global Cost, Pay Back Period and CO2 emission too. Since these are all important parameters to make the right choice, graphs that compare those values are obtained and they are represented like on the chart below.



For example, for the school in Istanbul, all measures have PBP (Payback Period) lower than 5 years and provide approximately 50% of primary energy savings and CO2 emission, but the GC reduction is more than 50% just for P30.

Also, any measure besides the criteria reported previously should provide proper comfort conditions in school. So, for example, if choosing the measures with the lowest GC could worsen comfort conditions, this option would be canceled.
There will always be different options that would be more suitable from different points of view, so depending on desired results, the final decision will be brought as a trade-off between different criteria.