Farinaz Falaki

RESIDENTIAL STOCK RECONFIGURATION AT NEIGHBOURHOOD LEVEL: FROM BUILDING RETROFITTING TO SUSTAINABLE DEVELOPMENT

INTRODUCTION

Current emissions of anthropogenic greenhouse gases, including carbon dioxide, have already consigned the planet to an increase in average temperature of the Earth in recent years that may exceed the critical threshold of numerous unmanageable and irreversible consequences, such as abrupt change in the climate system (Espinosa, 2006). The effect of natural variability and, more importantly, human activities on global warming of our planet is the subject of a huge number of recent studies in the course of the past twenty years (Dietz et al., 1997), (Ramanathan et al., 2001), (Karl et al., 2003) & (McMichael et al., 2006). This has created a worldwide debate on this subject which is emphasizing the need for long-term reductions of CO_2 emissions by various methods, especially through increased energy efficiency, renewable energy sources, and many other low-carbon strategies. Moreover, among the entire man-made factors resulting in CO_2 emissions, infrastructures and specifically building stocks are considered to be one of the most effective of all (According to USGBC and Architecture2030 in the United States).

On the other hand, the physical infrastructure in our neighbourhoods requires continual maintenance, repair, and significant upgrading to avoid falling into disrepair which causes economic, environmental and social costs. In doing so, in an integrated approach, we have the opportunity to address climate change adaptation, deliver reliable and efficient transport networks, improve health and well-being, secure a healthy natural environment, improve long-term housing supply, maximize employment opportunities and make our communities safer, more cohesive and more sustainable.

Recent years have seen much debate about sustainable neighbourhoods and how they can be created through the provision of sustainable infrastructure in new developments such as Millennium Communities, Carbon Challenge sites, zero-carbon cities and eco-towns (House of Commons, 2008). On the contrary, we need to focus on how we can improve the sustainability and quality of life in our existing places – especially given that at least 80 per cent of the buildings standing today will remain with us for another 40 years (Happold, 2010). In addition, retrofitting an existing building can most of the time be more cost-effective than building a new one (Paradis, 2012). Wherever it takes place, upgrading of existing infrastructure must have at its core the mitigation of, and adaptation to, climate change. However, such programmes can deliver a wide range of economic, environmental and social co-benefits, including better health, safer streets, more active citizens, better places for children to grow up, and reduced impact from extreme weather events. Our existing places can be transformed into environments that make better use of resources, have stronger, more resilient and more cohesive communities and competitive, robust low carbon economies. Therefore, economically, it is more beneficial to upgrade the existing than to demolish and reconstruct a new one.

Therefore, to address the environmental issues, such as an increase in greenhouse gas emissions, that may lead to an unsustainable living place and numerous irreparable consequences, several approaches can be practiced. In this paper, through a case study approach, an effort is made to emphasize the significance of reconfiguring our existing places at a local level as a solution to gain multiple socio-economical benefits, as well as having the opportunity to meet the requirements of National Planning for long-term targets for such issues as carbon dioxide emissions and energy consumption reduction.

SUSTAINABLE DEVELOPMENT CONTEXT AND RECONFIGURATION CHALLENGES

To assess sustainability, the question raised here is: what does a sustainable neighbourhood look or feel like?

Considering the Venn sustainability diagram (Adam, 2006) as the concept of sustainability, an area can also be studied from an economic, social and environmental points of view to be considered as a sustainable neighbourhood.

In economic terms, a neighbourhood which offers the residents local jobs, the opportunity of reinvestment and bringing in new incomes is defined as sustainable. In such a place, fuel poverty is minimized, the local economy is foremost and the buildings in this neighbourhood cost less to run.

From a social point of view, a community which provides maximum services, appropriate transportation choices and maximum quality and value of spaces is considered sustainable. In this neighbourhood, there is maximum community cohesion, interaction and civic pride. Fewer residents suffer from health inequalities and fear of crime. This society is more safe, secure and healthy.

In terms of energy consumption, a neighbourhood can be called sustainable when there is minimum use of virgin resources such as fossil fuels like oil, coal, natural gas, etc. and a maximum use of renewable, recycled and waste resources such as bio-fuels, geothermal, solar, wind and biomass. In such a neighbourhood, there is maximum link between resources used in the neighbourhood and accordingly energy security and energy efficiency is improved. In this place, biodiversity is enhanced and preserved. So water and air quality is maximized and there are minimum greenhouse gas emissions. Therefore, such an environment is also resilient to the impacts of climate change.

Why we are not observing the reconfiguration of infrastructures in every context?

There are several obstacles in the implementation of these kinds of projects. Some of the most significant of them are as follows.

It is impossible to measure all dimensions of the benefits of retrofitting buildings in a neighbourhood. The benefits can only be assessed by values such as costs per ton of carbon reduction saved. Some co-benefits such as health, aesthetics, social cohesion, etc. do not have a market value and therefore might be ignored by responsible sectors.

Practically, there is lack of sufficient coordinators and actors in this specific field. So the implementation of these kinds of projects is complicated.

There is a key barrier of ownership. Although buildings are mostly owned by individuals, there is a challenge in public acceptance and engagement in these projects. Moreover, usually such programmes of CO_2 reduction targets are integrated and involve all infrastructures in one neighbourhood: transportation routes, utilities, green infrastructure, etc.. The complexity of ownership of these infrastructures and the regulatory requirements result in involvement of a large number of organizations and authorities.

Budgeting and funding of such programmes is a big issue, as individuals are often unable to afford retrofitting expenses and the public sector might have difficulties from an economical point of view.

It is difficult to engage private sector stakeholders and investors into retrofitting programmes and connect public and private sectors. Items such as the lack of proven business models or accreditation systems are deterring private sector investments.

There is lack of integration of climate change and environmental concerns into urban policies and programmes, as well as a lack in action plans and strategic planning.

Lack of sufficient skills and the absence of accurate planning within local authorities is also a significant obstacle in infrastructure retrofitting. There is a strong consensus that unlocking the organizational and planning issues would be the key to enabling neighbourhoods to benefit from a more sustainable environment. Also, in order to start neighbourhood retrofitting, it is necessary to model the current situation and to simulate the future scenario. This will facilitate the assessment of the benefits and costs as well as decision-making and prioritising for implementation of the project.

OBJECTIVES OF MODELING

This work aims to show the potential of improving existing infrastructure at a local level by retrofitting buildings so as to deliver carbon emission reduction and adaptation measures while at the same time achieving wider economic, environmental and social benefits and improving the sustainability of the existing place and thereby improving quality of life in the long-term.

It introduces a socio-technical model which calculates the current amount of carbon dioxide in a local level and simulates its reduced scenario. This model is extendable to larger scales in future. Prediction of the current situation will allow for a better consideration of requirements. Afterwards it focuses on the changes resulting from energy efficiency measures, the deployment of renewable energy technologies and the use of non-technical interventions at a neighbourhood level. The model will be developed, validated and demonstrated using both existing data and new data collected in a neighbourhood from randomly selected buildings which are representative of the rest of the neighbourhood. Potentially effective socio-technical interventions can be implemented and the long-term impact of it to achieve a low-carbon community is the focus of this work.

RESIDENTIAL ENERGY CONSUMPTION/ CO_2 EMISSION MODEL

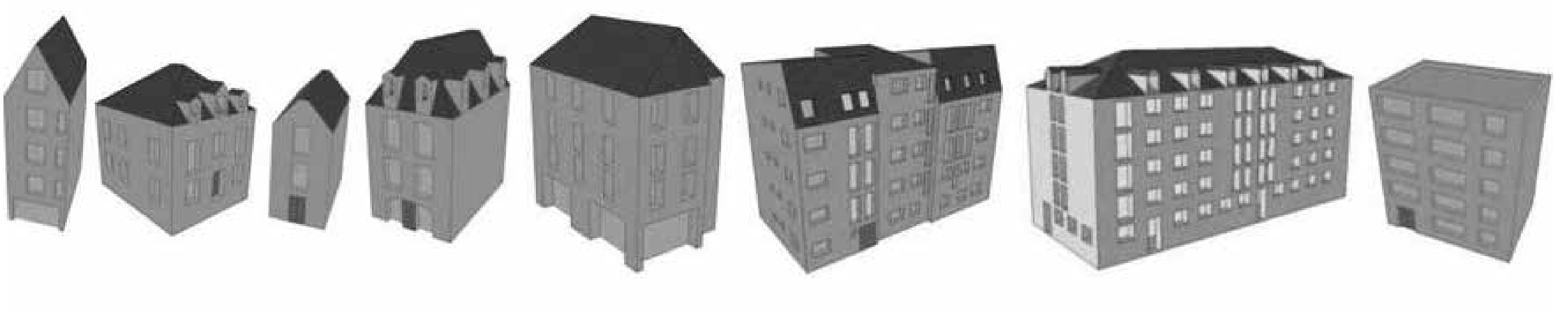
In a case study approach, this work verifies the method to assess the CO_2 rate in a neighbourhood and finds solutions for it afterwards. Hence, old neighbourhoods in the city of Tours has been selected as the study area. Numerous factors were involved and effective in the selection of this zone: feasibility & accessibility; variety in functions; variety in construction periods, construction methods, architectural styles and materials; being in need of retrofitting and being distinguishable by edges.

It is complicated to study the entire existing buildings for two main reasons. Firstly, data collection will be very time consuming. Secondly, it will be very costly. On the contrary, using a sampling method not only saves time and makes the project executable, but also improves the quality of work and its capacity of replication. Also the smaller amount of data makes it possible to ensure homogeneity and to improve the accuracy of the result.

So in this work, all buildings in the selected neighbourhood are given equal probability to be selected. Then 10% of the total number of existing buildings is chosen randomly. In this method, there is an assumption that this 10% are representative of the entire neighbourhood. According to the existing GIS map of buildings of Tours, each building is represented by one polygon with a specific identification number. Therefore, there are 280 polygons in the chosen area. So, a sample of 28 buildings – which is equal to 10% of the statistical population under study – are selected randomly and studied. Thus using Excel Rand function (random number generator), 28 numbers between 1 and 280 were selected.

Through site observation, the usage of Google maps and referring to local authorities' documentations, the necessary data can be collected regarding these 28 numbers. Thus, after studying and analyzing the samples, several types can be defined according to their similarities in their characteristics and features. Photography of the types allows for turning them into three dimensional models (See Figure 1). It is then possible to gain information from the simulated buildings. Numerous factors are involved in the calculation of energy consumption and therefore the rate of carbon produced by a building. Considering an MIT design advisor model as a base, some of these factors can be summarized as followed: 1) Area and volume of the building; 2) Glazing area; 3) Inertia of the building (thermal mass); 4) Heating systems; 5) Insulation; 6) Width of walls; 7) Material and area of exterior walls; 8) Size and type of windows; 9) Size and type of doors; 10) Roof material, type and area; 11) Floor type and material; 12) Built up floor area; 13) Orientation of the building; 14) Blinds, shutters or curtains.; 15) Occupancy load.; 16) Lighting requirement.; 17) Ventilation systems and 18) Behaviour of the occupants.

Many of these indicators vary from building to building according to their age. In fact, the historic data base related to the building age allows for understanding necessary parameters effective energy consumption (APUR, 2007). Considering the construction period of buildings and their characteristics, it is possible to define 8 different periods of architecture and archetypes for this particular context. The French revolution (1789–1799), industrial revolution (1760-1840), World War I (1914-1918), World War II (1939-1945), post-war renovation policies, change in construction regulations and modification of thermal regulation norms were some of the important historical periods which had effects on building styles (APUR, 2007).



1. 3D model of archetype 1 to 8 from left to right (created by Sketch-up software)
source: author

Type 1 (Before 1800): This first category is broad and diverse. It corresponds in fact to residential buildings built either before the French Revolution in the 17th and 18th century or in medieval ages and have been restored later after the world wars. Most of the buildings remained from medieval ages have wood-beams and half timber and wooden carvings and soft limes covered with thick layers stone wall of plaster coating. These buildings usually consist of a ground floor and 3 low-height stories and high slope gable roof. They are located in small, narrow plots and mostly all the site are allocated to buildings which are attached to one another.

Type 2 (1801 – 1850): The first half of the 19th century was contemporaneous to the arrival of the railways, canals, steam engine and industry to the city. The city was growing and its population was increasing rapidly. The plots were enlarged from 300 square meters to 600 square meters. The urbanization process started with the development of two to three story buildings along the main streets. Characteristics of buildings of this period are as followed: narrow windows, 4 or 5 storeys, a 30 to 40 cm semi-firm stone façade covered with a thick layer of plaster, small terraces. Construction methods changed gradually during this period.

Type 3 (1851 – 1914): This period is characterized by high facades, mansard roofs and in some rare cases pavilions. In these buildings, the proportion of height and width of the buildings are in a way that gives the building a narrow shape. The combination of brick and stone became more popular during these years.

Type 4 (1918 – 1939): Due to the First World War, no new construction was done from 1914 to 1918. After 1918, classical styles mostly disappeared and were replaced by eclectic treatments. In this period – due to the slow economic situation in France – there was less progress towards modern designs and buildings are simpler. Many buildings in this period had been damaged during the First World War and had been restored after this time. The façades are decorated with projecting bay windows in some cases. The buildings are provided with more and larger openings.

Type 5 (1945 – 1967): Due to the Second World War, no new construction was done from of 1939 to 1945. More concrete-related materials and styles were used in these years. Many mass social housing projects were started after 1950 due to post-war requirements. Many of these residential buildings were constructed by industrial methods of construction. Major characteristics of buildings in this period are simplicity, symmetry, repetitive layouts, geometrical effects and minimal landscaping. Climatic factors were considered in buildings only after this period.

Type 6 (1968 – 1974): During these years, prefabrication was developed. Curved and asymmetrical layouts became more common. Space, geometry and height were more emphasized. At the same time, the development of low-cost social housing was continued during this period.

Type 7 (1975 – 1989): Colour was given a more significant role in architecture of buildings, though still grey and white colours were widely in use. Pre-formed concrete components were used with wide expansion gaps between them. In this period, new modern architecture was evident which was based on traditional ideas and an organic relationship between building and site. The human scale was emphasized more. New buildings were attached directly to the existing frontages. Steel and glass in canopies were used more widely. Reinforced concrete was used in a more restrained style. Also high quality bricks were often used to stress artisanal traditions. Again the architecture moved from blocks of flats towards individual housing. So the number of individual buildings with the re-creation of traditional forms increased. Modern architecture was developed with respect to historic buildings. So using traditional materials, mansard roofs and traditional forms was still common.

Type 8 (1990 – present): In this period there was a rehabilitation of social housing. The buildings built in 1960s were developed to increase comfort, enhance heating and sound insulations. There were modifications such as installation of double glazing in the wooden facades; using insulating partitions in interiors or adding exterior insulations on the 60s buildings. During recent years, there are new building codes which dictate new thermal standards. So recently the appearances of the buildings are changing gradually. Indeed, buildings are often equipped with exterior insulation, which encourage the façade to have new materials, large panels and materials with more porosity. In recent years flat roof buildings are becoming more common in which the roofs are highly insulated against humidity (See table 2).

2. General characteristics of buildings of archetypes using 2CO2 model
source: Mindjid Maizia

	U-value of walls	Thermal mass	Insulation on walls	Insulation on roof	Average number of floors	Glazing percentage	Roof type
Before 1800	1.80	Very low			4	12%	Sloped slates
1801-1850	2.00	Very low			2	10%	Sloped slates
1851-1914	2.25	Very low			3	10%	Sloped slates
1918-1939	2.10	Low			3	15%	Sloped slates
1945-1967	2.80	Average			4	20%	Sloped slates
1968-1974	2.80	Average			5	15%	Sloped slates
1975-1989	1.50	High	X		5	20%	Sloped slates
After 1990	0.65	High	X	X	6	55%	Asphalt flat/ sloped slates

In order to calculate the rate of carbon emitted by a building, we should consider many factors. The factors that affect the result are defined below:

1. Building area (m^2): the built up area of the building
2. Building volume (m^3): the volume of the air in the building which is calculated by external dimensions of a building (According to a definition by European high quality Low Energy Buildings)
3. Glazing area (m^2): Windows, insulation glass, doors, glass bricks, glass tiles, skylights and any other glass components which are used in the envelope
4. [Thermal] inertia: measure of the rate of heat transfer that has an influence on the annual energy requirement for heating of a building and is calculated as the square root of the product of density (ρ), thermal conductivity (k), and heat capacity of a material(C) (High inertia corresponds to a thick concrete floor and iron or concrete structure while low inertia describes a light or timber-framed structure)
5. Climate: the hourly outdoor temperature, direct and diffuse sunlight intensity, rate of humidity and other weather characteristics which are varied from place to place
6. Temperature difference (ΔT) [K]: calculated by defining the required internal temperature for the buildings which is normally between 18 and 22 degrees Celsius (equivalent to 291 and 295 Kelvin) and the anticipated exterior temperature is supposed to present the normal lowest winter temperature (272 K for the example of Tours, France)
7. Building [solar] orientation: direction in which the glazing exists and the sitting of building with respect to absorption of free energy which has an impact on heating, lighting and cooling costs

Material	Cement	Wood	Aluminium		Stone	Glass
K-value (W/mK)	0.29	0.04 – 0.4	237 (pure)	120-180 (alloys)	1.7	1.1

3. Thermal conductivity of common materials
source: ISO 8302

Building components	**Details**	**K-value (W/mK)**
Roof	Aerated concrete slab	0.16
	Asphalt	0.70
	Bitumen layers	0.23
	Screed	0.41
	Stone chippings	2.0
	Clay tiles	1.0
	Concrete tiles	1.5
	Wood wool slab	0.10
Floor	Cast concrete	1.35
	Screed	0.41
	Softwood timber	0.13 – 0.24
Insulation	Expanded polystyrene board (EPS)	0.040
	Mineral wool batt	0.038
	Polyurethane board	0.025

4. Thermal conductivity of common components in building
source: www.bath.ac.uk

8. Area of the building envelope (m^2): area of the outer layer of the building (exterior walls) that separates the living spaces from the outdoor environment
9. Area of the openings (m^2): area of all doors and unfixed windows which can be opened to the exterior space and are located on the building envelope
10. Area of the roof (m^2): the surface of the final covering of the building
11. Area of the floor (m^2): calculated by multiplying the outer-to-outer dimensions of the floor; not considering the boundary walls,

Type of the window	Blind/curtain/shutter Without	Blind/curtain/shutter With	U-value [W/m2K]
Single glazed swing	x		4.95
		x	4.15
Single glazed swing (with air)	x		3.45
6 mm double glazed swing	x		3.25
		x	2.80
6 mm double glazed swing (with air)	x		2.45
Full height single glazed with frame	x		4.75
		x	4.00
Full height single glazed with frame (with air)	x		3.35
Full height 6 mm double glazed	x		3.10
		x	2.75
Full height double glazed with frame (with air)	x		2.40
Full height single glazed without frame	x		5.05
		x	4.20
Full height single glazed without frame (with air)	x		3.55
Full height double glazed without frame	x		3.20
		x	2.85
Full height double glazed without frame (with air)	x		2.50
Thermal insulated double glazed (4mm glazing + 12mm air + 4mm glazing)	x		1.70
Thermal insulated double glazed (4mm glazing + 12mm argon + 4mm glazing)	x		1.40
Thermal insulated double glazed (4mm glazing + 16mm air + 4mm glazing)	x		1.40
Thermal insulated double glazed (4mm glazing + 16mm argon + 4mm glazing)	x		1.20
Double glazed hard coat low-emissivity thermal reinforced	x		1.10
Double glazed soft coat low-emissivity thermal reinforced	x		0.75

5. Thermal transmittance of common window types
source: Calculated using 2CO2 model of Mindjid Maizia

Wall components (layer)	Thermal conductivity [W/mK]
Wood (softwood timber)	0.13
Steel	50.0
Hard limestone	1.7
Soft limestone	1.1
Gypsum plasterboard	0.25
Exposed mortar	0.94
Protected mortar	0.88
Reinforced concrete (2% steel)	2.5
Reinforced concrete (1% steel)	2.3
Concrete block (high density)	1.93
Concrete block (low density)	0.18
Concrete block (medium density)	0.57
Brickwork (exterior)	0.77
Brickwork (interior)	0.56

6. Thermal conductivity of common wall components.
source: Consultancy Study for Irish Concrete Federation

but taking into account the building outer walls and the inner walls.

12. Thermal transmittance (U-value) of the openings, walls, roof and floor [W/m^2K]: the rate of heat flow in watts through one square meter of a structure divided by the absolute temperature difference between in and out (well-insulated parts of a building have low and poorly-insulated parts of a building have high thermal transmittance). According to Fourier‘s law of conduction, heat flow is proportional to area and temperature difference and inversely proportional to the thickness of the material. The most important factor in the calculation of the U-value is the various layers and thickness of each part of the building. So, in order to measure the total U-value of a part of a building such as a wall, each layer should be calculated separately) (Darling, 2011)

Some roof types
Asphalt composition shingles
Wood shake
Metal roofing
Slate roofing
Composition slate
Ceramic Spanish-style roofing

7. Common roof types due to material.
source: Scudder roofing

Type of roofs	Examples
Flat roofs	Modified bitumen – Asphalt – Built up roof
Sloped roofs	Gable – Cross gable – Mansard – Pyramid hip – A frame – Hip roof
Eco-roofs	Cool – Green – Sod roof

8. Common roof types due to shape.
source: MIT design advisor

Type of insulation	Applicable on	Advantages
Blankets: Batts or Rolls Fibre glass; Rock wool	All unfinished walls, floors and ceilings	Suited for standard stud and joist spacing, which is relatively free from obstructions.
Loose-Fill (blown-in) or Spray-applied Rock wool Fibre; glass; Polyurethane foam	Enclosed existing wall cavities or open new wall cavities; Unfinished attic floors and hard to reach places	Commonly used insulation for retrofits (adding insulation to existing finished areas).Good for irregularly shaped areas and around obstructions
Rigid Insulation Extruded polystyrene foam (XPS) Expanded polystyrene foam (EPS or bead-board) Polyurethane foam Poly-isocyanurate foam	Basement walls Exterior walls under finishing (Some foam boards include a foil facing which will act as a vapour retarder.	High insulating value for relatively little thickness. Can block thermal short circuits when installed continuously over frames or joists.
Reflective Systems Foil-faced paper Foil-faced polyethylene bubbles Foil-faced plastic film Foil-faced cardboard	Unfinished ceilings, walls, and floors	All suitable for framing at standard spacing. Bubble-form suitable if framing is irregular or if obstructions are present. Effectiveness depends on spacing and heat flow direction

9. Type of insulations in buildings, their method of application and advantages.
source: DOE

13. Thermal conductivity (K-value) of the openings, walls, roof and floor (W/mK): the ability to conduct heat and the constant of proportionality (See table 3 & 4)(materials with higher K-value transfer heat faster). Therefore those with low thermal conductivity are widely used as thermal insulations. In addition, this value is temperature dependent. So, as the temperature increases in materials, they would be more conductive to heat)
14. Type of opening: differentiation of doors and windows which result in various thermal transmittances (See Table 5)
15. Type of walls: the structural component of the wall which is composed of several layers (See table 6)
16. Roof type: definition of roof due to its material, main structure component and/or shape (See table 7 & 8)
17. Floor type: categorized according to their variety in materials, configurations characteristics, etc.

- Major floor materials: concrete, wood, steel, plastics, adobe, autoclaved concrete, etc.
- Typical configurations: in-situ concrete, precast concrete, wood joists, steel joists, wood frames/truss, steel frame/truss, insulating concrete, structural insulated panel, etc.
- Key characteristics: field built, shop built, combo (shop and field), laminate construction, structurally adhered, pressed, stressed skin construction, etc.

18. Type of ventilation

- Mechanical: in which the building envelope is sealed and none of the windows can be opened. Thus, the ventilation is done by air conditioning systems;

Heating systems	Type of fuel	Location
Traditional furnaces	Gas – coal – oil - wood	Installed in the floor or on the living area‘s walls
Heat pump	Gas – electricity – oil	Pump: installed in the mechanical room, basement or kitchen
Radiant ceiling or floor heat	Electricity – natural gas – wood – propane	Installed in floors or ceilings
Hydronic heating (steam/hot water radiators)	Natural gas – oil -	Radiators : installed in each room Heating pump: installed in mechanical room or basement
Fixed space heater	Electricity – gas – kerosene	Installed on the wall
Air force (central heating)	Electricity – natural gas – propane – oil	Installed in the ceiling or on the floor
Solar PV	Solar energy	Panel: installed on the roof
Geothermal	Geothermal energy	
Combi	Varied (depending on the combination)	

10. Some types of domestic heating systems.
source: DOE, Energy Depot, Central Heating

– Hybrid: in which air conditioning is available but the windows are operational as well and there might be adjustable blinds or curtains to control the incoming light;
– Natural: in which no mechanical systems exist.

19. Air change rate: number assigned to air changes in spaces that have not been draught proofed which affects the energy calculated to heat the volume of air by the temperature difference (an amount of 0.34 watts is required to heat one cubic meter (1 m3) of air by one degree Celsius and to be on the safe side, a universal figure of 3 air changes per hour can be used with confidence)
20. Type of insulation: divided according to their variety in materials (See table 9)
21. Type of heating system (See table 10)

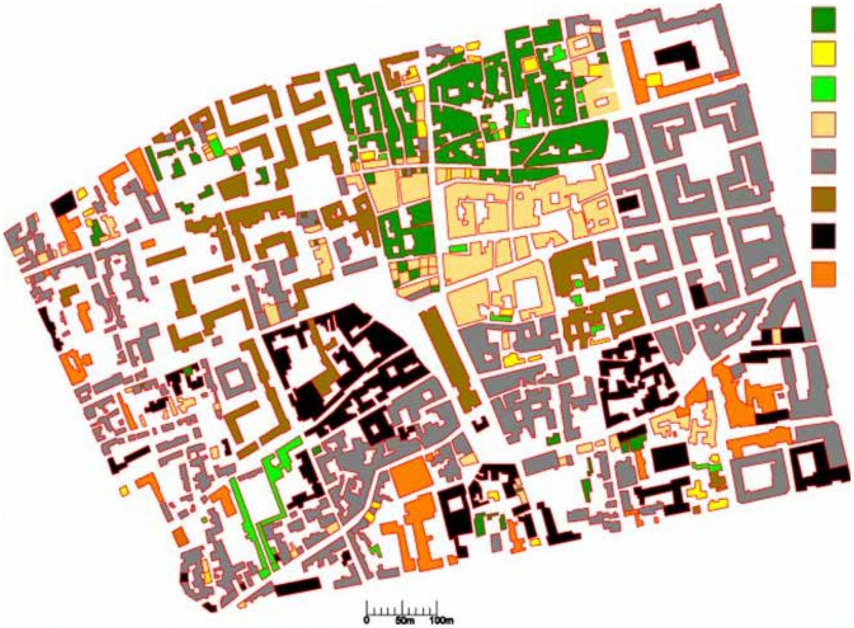
11. Results for all building archetypes current situation.
source: author

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Total building U-value	0.47	0.47	0.49	0.48	0.53	0.52	0.40	0.29
Total heat loss (W/K)	822	883	474	1072	2734	3385	5445	938
Heat transfer coefficient (W/m^{2}K)	774	799	448	1008	2480	3247	4675	638
F (coefficient of free inputs of solar or internal)	0.06	0.09	0.06	0.06	0.09	0.04	0.14	0.32
Glazing percentage (%)	0.12	0.11	0.09	0.13	0.17	0.15	0.16	0.55
Annual requirements per habitable area (kWh/m^2)	1354	630	830	804	1132	956	491	446
Total annual requirements (kWh/m^2)	48733	50364	28205	63506	156242	204544	294535	40178
Annual consumptions per habitable area (kWh/m^2)	1962	663	873	846	1192	1006	517	470
Total annual consumptions (kWh/m^2)	70627	53014	29690	66849	164465	215309	310037	42293
Total emissions of CO$_2$ (Tones)	14.3	9.5	5.3	12.0	29.6	38.8	55.8	7.6

OUTPUT RESULTS FROM THE MODEL: CURRENT SITUATION

After transforming the above factors into a mathematical model, there would be a possibility to input various data base for each archetype. The achieved outputs are summarized in table 11.

After the calculation of the rate of carbon for each defined type, we generalize the data thus generated for the whole neighbourhood. In this phase, according to the existing local plans of the neighbourhood and with regard to the polygons representing each building (see figure 12) and the data base which indicate height of each building, it is possible to calculate the volume of each particular type. Due to the rate of emission per cubic meter of each type of building, a specific number would be gained which is the total CO_2 emission for the entire neighbourhood. Such generalizations can be considered for larger scales (see table 13). Afterwards we can extend the study to the regional and national scales if required.



12. Schematic typology map of the study area in Tours.
source: author

Archetype	Model building volume (m^3)	Total CO_2 emitted by model building(tones)	Kg CO_2 per $m^3$of model building	Total volume of each type (m^3)	Total CO_2 emitted by each type (Tones)
1	425	14.3	33.6	477964.68	16059.61
2	704	9.5	13.4	50015.16	670.20
3	286	5.3	18.5	66225.51	1225.17
4	982	12	12.2	397943.55	4854.91
5	1749	29.6	16.9	1512729.36	25565.13
6	3257	38.8	11.9	620036.70	7378.44
7	11460	55.8	4.8	762434.55	3659.69
8	1120	7.6	6.7	441881.82	2960.61
Total CO_2 of the neighbourhood					62373.76

13. The emitted rate of CO_2 by each archetype and total CO_2 emission of the neighbourhood in current situation.
source: author

OUTPUT RESULTS FROM THE MODEL: RETROFITTED SIMULATION

In order to reduce CO_2 emissions, energy consumption should be reduced. Therefore six main subjects play a substantial role in this decrease (See table 14).

Diverse methods are available for reconfiguration of a building:

- **Enveloping**: This includes removing faults from all external envelopes such as roofs, gutters, chimneys, openings, glazing, walls, etc. It would reduce the heat loss and therefore reduce the consumption of energy which would lead to less production of carbon dioxide.
- **Adding wall insulations**: It is also possible to use a kind of plaster inside which works like an insulator. In addition there are some foam panels or insulating paints that can be applied inside. Moreover, some kinds of insulations can be applicable on an already existing finish of a wall. Therefore they are suitable for retrofitting and can be applied mostly by spraying. Some of these insulations consist of rock wool, fibre glass and polyurethane foams.
- **Adding thermal mass to the interiors**: Adding bricks, blocks, stones or such materials in various places as well as tiling the floor can be beneficial.
- **Using green roofs**: To convert the roof to green space, we need to know whether the structure can support the considerable additional weight of soil, and the existing roof can be sufficiently water tight. So this option can be considered only in newer buildings.
- **Upgrading the glazing**
- **Installing solar photovoltaic**: Solar PV is capable of generating electricity by daylight and can be installed on roofs. Each kilowatt-peak of electricity produced by solar panels can reduce carbon dioxide emissions around 450 kilograms comparing with fossil fuels.
- **Using green infrastructure**: Usage of trees with falling leaves in front of the buildings‘ windows to exclude summer sun with their shades and catch winter sun would be very effective.
- **Compensating heat loss**: This can be done in several ways including using passive solar heating

So in order to make a simulation for the CO_2

14. Six influential subjects in CO_2 emission reduction.
source: author

Building envelope	**Heating systems**	**Ventilation Systems**	**Solar control & cooling**	**Light & electrical Appliances**	**Management**
Doors	Heating installations	Natural ventilation systems	Shading & glare protections	Lighting systems	Energy audit techniques
Windows	Domestic hot water	Mechanical ventilation	Cooling systems	Electrical appliances	Commissioning
Insulation	Energy sources	Hybrid ventilation systems	Air-conditioning systems	Day-light technologies	Education & training
Over-cladding systems	Control systems	Control & information	Control systems	Control systems	Non-investment measures

reduced scenario, it is crucial to consider retrofitting methods for each type separately according to its specifications. As an example, buildings of type 1 are located in a heritage conservation zone, so we can only apply the following:

1. Applying a thin layer of insulating plaster inside the exterior walls which is applicable on the existing wall finish;
2. Adding blinds, shutters or curtains from inside to the existing windows;
3. For roofs: Installing polyurethane foam boards under the roof;
4. Sticking woods and a layer of foam on the existing finish floor;
5. Using multi-resources for heating (E.g. heat pump and electricity) and connecting to central network of energies.

So the same approach was taken toward all archetypes and the simulated U-values, K-values, materials, opening types, etc. were chosen one more time and applied on the model to have the results for the future scenario (See table 15).

The retrofitting measures resulted in 11903.72 tones of CO_2 in the neighbourhood, which means that, with this approach, the amount of carbon dioxide is reduced by an approximate rate of 70%.

CONCLUDING REMARKS

The CO_2 emission calculation allows for a current situation assessment as well as for a future scenario and gives the opportunity to compare the two and plan for its implementation. One of the advantages of this model is that it is adjustable. This feature allows the model to adapt itself to modifications (adding double glazing, changing heating system, insulating the envelope, etc.). The simulation enables us to study the influence of each factor of energy consumption and CO_2 production and to analyse the feasibility of the project in terms of economy. The method used to evaluate the amount of CO_2 can also be used as an assessment tool for the future construction of residential stocks.

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Total building U-value	0.42	0.27	0.43	0.35	0.39	0.38	0.29	0.25
Total heat loss (W/K)	676	455	364	675	1523	2055	4133	806
Heat transfer coefficient (W/m^2K)	628	376	338	612	1278	1918	3374	511
F (coefficient of free inputs of solar or glazing percentage (%)internal)	0.07	0.18	0.07	0.09	0.16	0.07	0.18	0.37
Annual requirements per habitable area (kWh/m^2)	1099	296	627	488	583	565	354	357
Total annual requirements (kWh/m^2)	39579	23658	21310	38581	80496	120817	212532	32165
Annual consumptions per habitable area (kWh/m^2)	366	99	209	163	194	188	118	119
Total annual consumptions (kWh/m^2)	13193	7886	7103	12860	26832	40272	70844	10722
Total emissions of CO_2 (Tones)	2.4	1.4	1.3	2.3	4.8	7.2	12.8	1.9

15. Results for all building archetypes in retrofitted simulation.
source: author

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