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Retrofitting for Climate: Developing a Future System

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Abstract
We use two recent quotes to describe the current situation. Prof. Omar M. Yaguhi, at the 2025 Nobel banquet, said: "And on climate, the hour for collective action has already arrived. (The) Science is here. What we need now is courage." Prof. Francesco Corvaro, said: "As Italy, at the heart of the Mediterranean, I believe that we must try to turn our role as an energy hub into a role as a resilience hub for Europe, using infrastructure, diplomacy, and technology together to support both security and decarbonization". These two quotes indicate a merger of thinking that is focused on technology integrating science and socio-economic priorities. Adding to that a North American concern about a growing efficiency gap between construction and the manufacturing industry, one obtains what Kuhn [1]. Defined as pre-conditions for a scientific revolution. Still, recognizing engineering, which includes both science and practical know-how, we call it a technological revolution. Therefore, this paper will explore how a change in the thinking paradigm can permit extrapolating the current technological trends into a national program for universal retrofitting of residential buildings to slow climate change. This program will deliver a near zero energy and carbon emission technology and address environmental control in different climates.

The Half Century of Chaotic Growth in Construction
Fifteen years ago, at a Building Science conference in Nanjing where a group of Western met Chinese scholars, we concluded that neither North American nor European scholars knew how to design environmental protection of residential building for a permanently wet, continental climate. To solve this problem, we created an international, virtual Environmental Quality Management (EQM) network, which is now dissolved as the problem has been solved.

The First Three Decades After WWII
Bomberg and Onysko analyzing Canadian construction history observed that building science principles were derived from observations of the performance of the existing buildings. As in the adage, "necessity is the mother of invention", most of the innovative thinking of the1920s and 30s came from the Prairie regions of North America [2]. The climatic extremes fostered the need for buildings with envelopes that provided protection and environmental control for human occupancy in a durable way. Failures provided important lessons, and they still do. In 1971 lecture, Hutcheon made statements that are as current now as they were at that time [3]. There is a vast difference, however, between trial-by-use as the primary way of arriving at prediction and use as a confirmation of prediction based on evidence. Tradition places the emphasis on how things should be done; science sets out to explain why so that the experience can be carried over to different materials and circumstances." "Research may be considered as the acquisition of carefully planned selective experience. It may be used to provide predictability about a limited situation, without regard for wider application, or it may be directed more broadly to an understanding of the functional relations involved in some more general situation Neil B. Hutcheon is considered as the father of Canadian building science, he introduced the concept of building science as the practical means of ensuring predictability of buildings' field performance, and he clearly states that in the post-war construction boom the vision for residential buildings was defined by tradition. Still, looking from the science point of view, Bomberg et al.,call this "the period of oversimplifications" or using language of Einstein a period of simplistic solutions in contrast to simplified solutions. Figure 1 shows the demonstration of physics in grade 6 of a primary school, and demonstration of physics in a typical construction of exterior thermal insulation composite system [4].

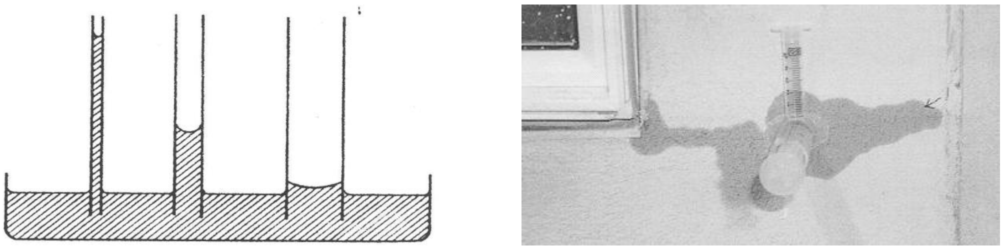

Figure 1: (a) Water Suction in the Capillary and (b) in a Small Crack in the Finishing Layer on Exterior Thermal Insulation. Here is Also a RILEM Tube to Measure Water Absorption Rate of the Plaster (From Own Archives)

One learns in primary school that water climbs several centimeters in small capillaries, but Figure 1 shows simplistic design with two types of failure. In the fist, one forgets the temperature difference on both sides of thermal insulation that will cause a difference in the dimensional changes of the finishing layer, the second time one forgets that porous material shrinks or swells with moisture content changes creating also a miniscule crack between the masonry wall and the window frame. These failures would not occur in the 1930s because we used multi-layered plasters and different ways of mounting windows.

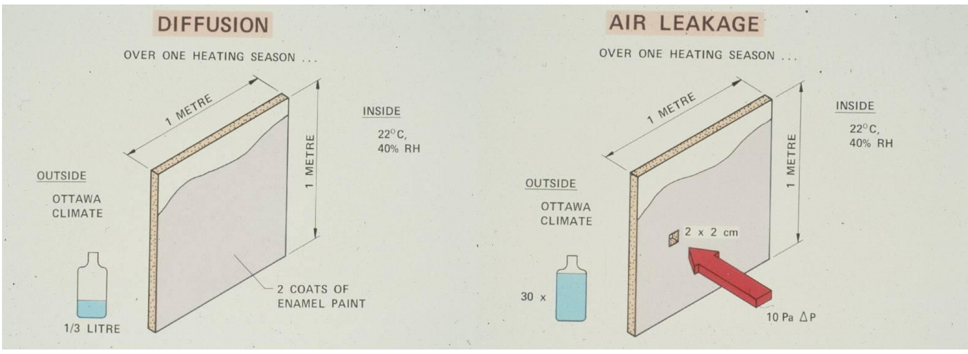

Figure 2: Moisture Accumulated Over One Winter Season (a) From Diffusion in a Wall Without Water Vapor Barrier and (b) From Air Leakage in the Comparative Situation of Ottawa, Canada Climate (From own Archives)

Only the moisture was mishandled. Air entry for ventilation or uncontrolled air exchange through the building enclosure was first neglected and layer became subject to" a green simplification" i.e. opening windows for ventilation of small buildings. Air distribution inside the building, interzonal air flows, air flows though connecting interior walls are even today not considered by in low-rise buildings. The senior author, who at the end of 1950s followed a building technology program of a German university learned from the handbook about typical air flows per 1 m of the window perimeter. One may observe that knowledge of environmental factors in central Europe disappeared because there was no cost of energy, and wet and leaky buildings worked well because we were using more energy.

The 1973 Energy Crises Introduce Ecology into the Construction Language

Figure 3: The First Passive House in the World, Concept of U of Illinois, Construction City of Regina, Saskatchewan, Canada, Designer Harold Orr PE (awarded orders: Pioneer in Germany, Companion of Canada, (From Own Archives)

The new technology was immediately improved by the builders. The concepts of air tightness and superinsulation were appreciated, still the reduced heat losses tempted builders to change more by replacing expensive heating systems with simple electrical baseboard heating that also eliminated chimneys. This changed the ventilation pattern and caused the "sick building syndrome" (insufficient natural ventilation and "wet attics" (water vapor condensation on upper floors). In response the Canadian Building Code required mandatory mechanical ventilation for all residential buildings.

Two Governments Interventions to Create the First Technological Revolution in Construction Industry

It took more than five years of surveys and detailed analysis to realize that building shown in Figure 3 represented a new construction system, and that the building must be designed as a system, not as an assembly of superior materials. Still, a lot of people do not see the difference between a building assembled with ever improving materials and a building created as a system. To illustrate significance of other materials in the assembly we report an airtightness test on a standard wood frame wall assembly, where an airflow rate was measured at 50 Pa pressure difference at the floor wall junction in with exterior sheathing was ascribed a value of 100 %. In the first approach we replaced standard exterior sheathing with airtight sheathing. This reduced the airflow measured by about 30%. In the second approach we also add a flexible thin layer of thermal insulation to provide better contact between wall and floor surfaces, what reduces it further by about 20% and added interior molding that keeps interior drywall tight to the wood frame that made a further reduction of 25%giving the total reduction 75%. Thus, in this example, the contribution of other materials was much higher than the improvement of the main component of air tightness. The above numbers are only to highlight contribution of other materials to the system performance because measurements under steady pressure differences do not represent dynamic response of an exterior wall to wind pressures. Realizing that we were facing a major change in thinking paradigm, Canadian Government jointly with the builder association, central mortgage corporation and some universities undertook a critical decision creating a national research and demonstration program called R2000 (R stands for thermal performance and 2000 was an expected time to achieve the thinking paradigm change [5]. The R2000 program established a few measurable functional requirements for the complete system and opened a competition for several teams in various provinces to build demonstration buildings in any way that chose. As soon as the concepts of R2000 were showing in practice, the US instituted "Building America" program were leading consulting teams we funded 50/50 by public and private sources and like R2000 had to deliver a specified set of technical requirements [6]. In contrast to Canadian program that was designed to introduce the technological revolution and was restricted to several demonstration projects per province, the American program the American program required cost reduction of the technology as builders had to pay the 50% of the R&D cost. Effectively, these two programs changed construction of small, residential buildings from fragmented to holistic basis. These two North American (NA) programs collaborated with each other and introduced for a major public education initiative to change the design paradigm from traditional improving construction materials to designing a system in which materials are selected to fulfill the system requirements. In economic terms, they represented investment of tax aper money in the market value of new technology (whatever it is) by creating a market pull, i.e., market preference to certified R2000 or Building America houses over the others. Obviously, the blueprint for these two programs was the first technological revolution in car manufacturing. In 1913 Henry Ford changed paradigm of car manufacturing, instead of workers coming to the car, the car came to the worker. In 1910 Ford sold 19,000 cars in 1920 it was 941,00 cars and the price was reduced 5-fold. In NA the housing cost remained the same but Figure 4 shows how the comfort components increased.

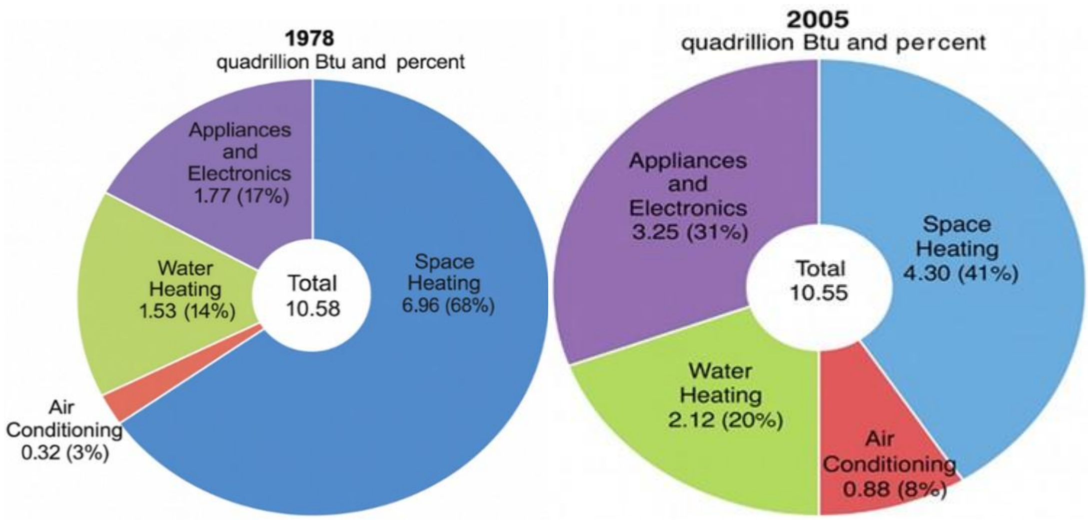

Figure 4: Effect of the First Technological Revolution in the US, the Same Use of Energy in Buildings but Space Heating Reduced by 25% and Comfort Component Increased from These Savings

In effect, in the 1990s the first technological revolution was completed and build as a system replaced traditional thinking.

Streamlining the Design Process: IDP (Integrated Design Protocol) and Computer Modelling

In the 1990s, the uncertainty in design objectives was reduced by a compromise. As predicting energy consumption was beyond the capability of architects and structural engineers, an energy modeling expert was added to the IDP team [7]. At the same time, the analysis of environment in buildings was moved to a conceptual stage. This process was called a design charette, as during the French Revolution charette, was the carriage taking the condemned to the guillotine. The IDP concept spread worldwide. Why? Is it because IDP creates a common vision of the building for the design team? Perhaps, but the real reason was economics. By placing the environmental decisions upfront, IDP reduced the cost of design. In the same period computer modeling entered the process of design (Figure 5). Computer modeling was used in advanced Building Physics groups since 1971 but only in mid 1990s with the presence of energy modeling expert came some durability modeling where climatic effects are critical.

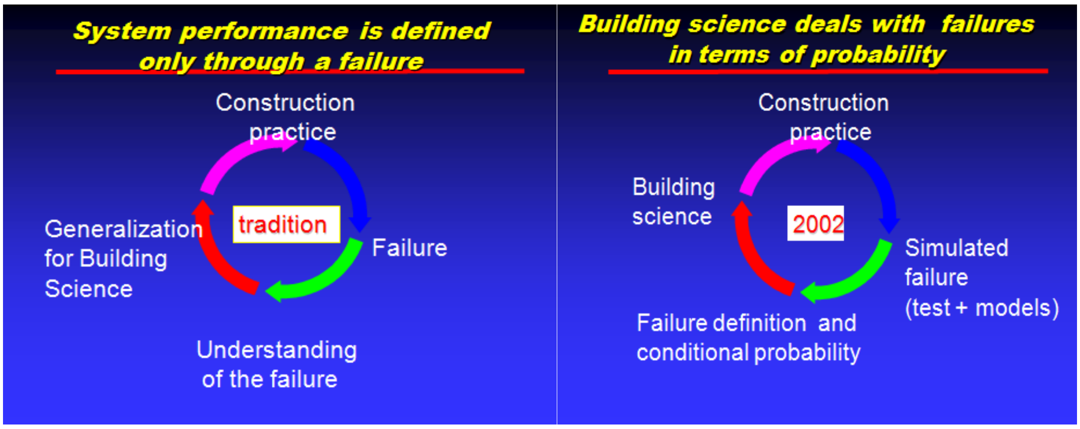

Figure 4: Modern Building Physics Can Replace Most of the Tests by Computer Modeling if the Model is Calibrated with Real Case Data (from own archives)

Other Lessons from the Past

With progress of globalization various national research centers were either closed or required to collaborate with the local industry, dropping future-oriented work.

Thermal storage,
Adaptable indoor climate,
Ecological definition of low energy buildings,
Reference cost of (c) buildings for cost comparison,
Holistic and balanced approach to retrofitting,
Field verification of energy computerized models and guidelines
Occupant involvement in tailoring own indoor climate

Table 1: Examples of Neglected Areas in the Field of Building Environment and Energy

Code and standards often increase confusion by ascribing requirements to specific materials. An example is a water vapor barrier (retarder), that had been requested to have permeance of 57 ng/ (m^2 s Pa) or less, (one perm in Imperial Units). This was a characteristic of 19-mm thick wood plank used in traditional rural construction, an excellent benchmark for a moderate climate. Yet as range of limiting values for country like Canada is 100-fold, this is too low for cold climates and too high for moderate climates. Identical problem is with requirements of air tightness. Figure 5 shows computer calculated moisture content in glass fiber insulation in wood frame houses located in different climates of Canada and Finland when indoor air with temperature 21 oC and 35 %RH enters the wall at the rate 0.9 l/(m^2s)

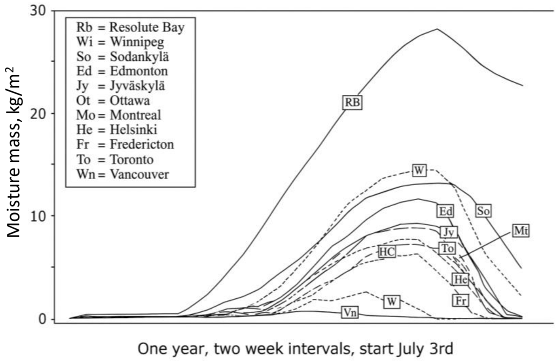

Figure 5. As the Acceptance Criterion is no Increase of Moisture Content for one Year, the Limiting Values are Shown for Toronto or Helsinki. Still, for Half Cities Shown in Figure 5 it is Too Severe and for the Other Half is not Severe Enough. From [8]

These two examples indicate that if mandatory evaluation is needed the level of comparison should only be a benchmark and the actual criterion should be climate-dependent instead of one strict pass or failure criterion.

Period Between 2000 and 2025 Creates Pre-Conditions for the Next Technological Revolution

In the first 25 years after WWII, we did not pay attention to the cost of energy, in the last 30 years, in theory, we were focused on energy but in practice, we were increasing the cost of living until we reached the crises of affordability.

Need for Paradigm Shifts in Contemporary Economics

Pundits bring to our attention several problems facing construction today (Table 1).

Climate change
Changes in information technology
Biological risks for occupants
Cost optimalization of technology
Changes in economics brought by globalization
Changes in economics brought by demographics

Table 2: Current Challenges in Construction Today

Some of the most important changes take place in information technology: Artificial Intelligence is replacing traditional modelling, 3D printing, internet of things and new types of software that impact smart buildings. Smart buildings are the focus of young and educated people, while old people have increased demands for better indoor environment and comfort. New on the list are biological considerations such as risk of biowarfare or significant changes in ventilation. Instead of dilution, that could have been achieved by opening windows, SAR-coV2 pandemics showed that we must use air filtration, which in turn requires a difference in air pressure in the dwelling. The last item may appear as a small change, yet because the difference between the vertical position of the analyzed space and the neutral plane of air pressure affects air pressure in the dwelling, each floor must be separated from other floors. No vertical shafts or staircases connected with different floors can affect air pressure on the given floor. In other words, each building is designed as several individual floors, each containing dwellings and communication space.

Furthermore, construction of small residential houses is under economic pressure as its efficiency has not increased, while efficiency in other manufacturing in last 50 years has increased 3-fold. Still, the single most annoying aspect of construction today is probably the growing difference between efficiency predicted and achieved in practice.

A Growing Gap Between Energy Efficiency Intended and Achieved in Practice is Expected

Figure 3 showed what we intended, i.e., reduction of space heating, indeed took place. Still, all energy savings went for the increase of occupant comfort, because this is a public demand. Covey [9]. In his seminal book, "7 habits of most effective people" explain that one should start with the end in mind, yet it means one should have a quantified vision of the building performance Still, no scientific vision of the construction process exists, because the tradition was replaced by several different options where only some functional requirements were defined. Despite Hutcheon calling for increasing predictability of building performance (and defining building science [3]. To highlight that shortcoming of building physics), nothing was done. As it is convenient to base legal system on modeling it is therefore necessary to calibrate the models. Still, these models are to be used as real time performance, they must be calibrated.

The Need for Retrofitting Vision

We need a vision of retrofitting. Such was also a conclusion 2010 Nanjing conference of Building Physics because climate in this region of world is humid all year round [10]. Unfortunately, building science in America and has been stagnant for years (Bomberg et al. [11]. And building physics in Europe suffered from the "green simplification" when house ventilation was replaced by opening windows. Now lessons from pandemics brought air filtration to the front of indoor environment considerations. Water, with the capacity for heat storage being four times higher than air, and must remain as the carrier of thermal energy, but air movement being involved in most of environmental considerations is the second key component of design for energy and environment. Thus, the retrofitting vision must include integration of these two sub-systems in the process of monitoring and modelling to evaluate and improve performance of new technology for retrofitted dwellings and buildings. There is another reason for which the academic community must publish a vision for buildings renovation, rehabilitation, thermal upgrade, modernization and many of those words used by politicians without any deeper understanding -- because in most cases their green subsidies to the marketplace are slowing technology process instead making it faster and easier. As an example, the past administration in one EU country was supporting local manufacturers of heat pumps and their clients at the same time. What they achieved was an increase of the market price of heat pumps and proliferation of the worst technical solutions e.g., so called "heat pump operated hot water tank" had 19% energy from the heat pump and 81 % of the direct electrical heater. If there was a scientifically documented vision for retrofitting, the level of political ignorance would be reduced.

Universal Technology for New Construction has Already Been Developed in 2020

A confidential report of National Research Council of Canada (report 1639 from December 1947) provided field measurements on two one story huts. Metal pipes were placed under the whole ground floor (on a partly insulated concrete foundation), to provide hydronic heating to the building. Each hut had a 1.2 m high crawl space above the heated slab and a living space about 20 m^2 square. The report presented amount of heat supplied to the building as the function of the exterior temperature and applied level of ventilation in the range between 1.5 and 4 ACH. While this "thermo-active" system was used to establish the magnitude of heat losses in relation to climate and ventilation needs it still was an unpublished template for future developments. About 60 years later, a Hungarian inventor [12,13]. Used a hydronic heat exchanger in the additional concrete slab located some distance under the building. The geothermal hydronic heat exchanger in Hungary, did not provide enough energy and a heat pump was added to the ventilation system. At the same time a PhD student in Syracuse University [14]. Built a heat exchanger circulating air in walls, using a split-level heat pump operating on a geothermal water tank located underground. About the same time, a team of motivated people in the city of Montreal, Canada, realizing that success requires addressing many design details, developed integration though a stepwise construction [15]. During the span of 10 years they reduced the 92 percent energy use, as postulated by the Lawrence Berkeley National Laboratory (LBNL, see [16]). The need for universal technology that was made clear during a Westen-Chinese building science conference 2010 in Nanjing. At this time, thermal mass in wood frame home was studied by Mattock [16]. A demonstration home was built and operated in Hungary (Kisilewicz et al. [12,13]), test building operated in Syracuse [14]. And the multi-stage residential district was built in Montreal [15]. All these are steps towards technological revolution. A team of motivated people in Montreal, Canada also started a step of technological revolution in construction industry independent from the NA system transition. Recognizing that building must satisfy the code requirement, this was defined as the starting point. All improvements may now be considered as retrofitting. If so, additional work is what one calls in economics "value added", and such a process can be mortgaged based on its current value. Using this formula, they were using a series of short-time loans. During 10 years of multi-stage construction, they reduced 92 % energy consumption from stage 1. Atelier Rosemount in Montreal, Canada had some luxury apartments with south and north exposures to enable cross ventilation, and social dwellings with the cost of a fraction it but nearly the same comfort of life. This project broke also barriers between new buildings and retrofitting and barrier of affordability.

Figure 6: An Affordable, Low-Rise, Energy-Efficient Multi-Unit Residential Building "Atelier Rosemount" in Montreal, Rain Retention Basin in the Bottom Right (Credit Nikkol Rot [15])

The retrofitting included the following steps:
• High performance enclosure; common water loop; solar panels resulting in 36% reduction.
• Gray water, the passive measures of energy reduction give 42%.
• Heat pump heating—all passive measures give a 60% reduction.
• Domestic hot water with evacuated solar panels, a further 14%.
• Photovoltaic panels reduce the total energy to a total of 92% reduction.
• Based on this project we propose a two-stage construction process that alleviates conflict between investors and society.

The second step in the path to the second technological revolution in residential buildings technology came in ASHRE (American Society for Heating and Refrigeration Engineers) 2020 competition for sustainable technology where the 1st place award went to a building in Tokyo, Japan, with integrated hydronic, heat pump based radiant heating/ cooling and ventilation called thermo-active system [17]. Thus, on the basis of the first series of network publications [17-19]. And the second series (called EQM parts 1 to 4 [20-23]) work of Atelier Rosemont, Montreal, Canada [15]. Hungarian inventor work [12,13]. Tokyo design [17]. Older work in US passive house institute [24,25]. And zero energy house in Vancouver [26]. Work at Syracuse University, NY, USA, and the American LNBL which quantified requirements for new construction and retrofitting, the EQM team can state [15,16].

A Foundation for Universal Technology of Sustainable Buildings with Near Zero Energy and Near Zero Carbon-Emission has Already Been Established in 2020

Despite this observation, neither multi-stage construction nor thermo-active (TA) technology became widely used. It became evident that current linkage between academic work on energy and indoor environment and construction practice is too weak to impact the marketplace in any developed country.

Creating Passive and Thermo-Active (PTAC) Retrofitting Technology is the Final Step Towards the Second Technological Revolution

The concept of daily interaction of the cluster of buildings (or a district of the city) with the smart grid was easy, we need a short-term storage in buildings about 16 hours. What about winter periods of extreme weather? This was a subject of a guess. In a traditional energy analysis, there was no consideration of period in which the building must withhold independence of electrical grid. At the moment we consider long-term storage of building cluster as one week. Thermal storage may be less economic than industrial electrical storage for a period longer than a week. Thus, future electric grids must accommodate season to season, energy load changes while buildings will assist the grid primarily in daily load equalization.

Cost Reduction in Decarbonization Process

Torrie and Bak writing about Canada, highlighted that despite dwellings with a total floor area of 2.1 billion square meters and 65 million tons of carbon emissions per year, (2/3 natural gas), Canada has no pathway to future. In 2019 Canadians spent more than $30 billion on space heating [27]. For a 10-year transition to a low energy, with a yearly average of $36.7 billion per year, the cost of carbon emission is $141 per ton (about US$ 100,00). If a new technology would reduce the price by 30% with 30 % increase in carbon efficiency and the volume of retrofitting could grow 3 folded the cost of emissions would be reduced 10-folded. We take this calculation as a working objective to slow the rate of climate change. Thus, a scientific revolution in construction will provide a win-win solution for society, economy, and the building's occupants. Society wins with slowing climate change, the economy with plenty of local jobs, and occupants with affordable, excellent indoor environments. As builders do only what society wants them to do, society must demand buildings to have zero carbon emissions and occupants to have a higher comfort of living.

Benefits of PTAC Technology

PTAC technology extends the passive house methodology with the use of:
• Ecological definition for low-energy building cluster in new or retrofit construction is as follows: for a low-rise (1 to 3 stories incl.) is 70 kWh/(m2 a) and for a mid-rise (4 to 11 stories incl.) is 100 kWh/(m2 a)
• The two-stage (or multi-stage) construction process is used to modify the pattern of financing.
• A short-term thermal storage (16 hours) to reduce daily variation of the loads in the electric grid, and a long-term (168 hours) thermal storage to reduce seasonal climatic extremes of hot week in summer or freezing cold week in winter
• Building automatics to control contribution of thermal mass and additional water thermal storage linked water-sourced heat pumps and for new construction also with solar panels.
• Adaptable indoor climate achieved with HVAC integrated with the building structure
• A monitoring and performance evaluation (MAPE) system to optimize energy and indoor environment during operation of the building.
• Climatic District Network (CDN) to connect the Passive and Thermo-Active Cluster (PTAC) building to the next building or to apply in series of buildings in a city district [28-31].

The word cluster in the above definition means a cluster of passive and thermo-active methods and a cluster of buildings (in the extreme case it is one building with the surrounding ground). Montreal project [15]. Showed how much energy can be reduced by different actions. In the first step, high level of thermal insulation and air tightness, reduced energy consumption by about 40%. An air-sourced heat pump was added to the passive measures in New York State, and energy reduction reached 55% (see construction process and quality assurance). A Ph.D. that reviewed co-simulation as an improvement for energy modeling) showed the limit of passive measures with an effective heat pump application at 60%. To reach more than 60% one needs to use additional measures, e.g., geo-solar engineering or a modification of the energy supply system. The latter is postulated in the PTAC technology for retrofitting [32-37]. Experience from California supports ventilation with variable rate and consideration of microbiological pollution requires air filtration. The ventilation system in PTAC technology uses air gaps created between existing walls and a new heating/cooling system. As we said in the introduction in this paper we propose only a template for different options. It is for a designer to select the water tank capacity, power of the WSHP that operates in the night only, or extend hours of WSHP operation, use one- or two-step water buffer system, and means to ensure the minimum temperature of the low HP terminal. If the supply system is too expensive, the designer may increase the level of thermal insulation or introduce phase change / reflective surfaces in the heating /cooling panels. Alternatively, one may increase the area of wall retrofitting.

Providing Energy to the Lower Terminal of WSHP

Heat pumps are the preferred choice because of the energy multiplication effect. Still, there are different types of heat pumps and In PTAC technology we use water-sourced heat pump (WSHP with two water tanks: (1) Domestic Hot Water (DHW) tank, and (2) cold water tank (CWT), The latter tank functions as a lower terminal of the heat pump. Using a water-sourced system brings new consideration about the lower temperature limit. For instance, when temperature in cold water tank falls below a specified limit, e.g., 10 C, an electric heater starts adding energy to the water. Still, electric heating has an apparent coefficient of performance (COP) of one, while WSHP has typically COP higher than 4. It makes sense to replace electric heater by an additional air to water HP, (monobloc). In such a case the temperature of CWT may be increased to permit a higher COP of the WSHP Other benefits of WSHP are increase of heating or cooling efficiency, presence of hot and cold water though whole year, easy integration of hybrid solar panels or gray water, and district climatic network.

An Invention of a District Climatic System to Replace the District Heating

This PTAC technology introduces an innovation in the climatic district network (CDN) that may also be applied to historic buildings by pairing them with an adjacent standard building. In this manner, the pair of buildings are included in a local district heating/ cooling system. District heating, cooling, and ventilation systems eliminate the difference between a single building or district of the city. As PTAC technology includes thermal storage and water tanks may be located underground [36,37]. The district climatic system may either be a part of the building or the energy distributing system. The summary of the research on air-earth heat exchangers implies 1 m depth in Central Europe. If a low-density, (about 10 kg/m3), polyurethane foam fills this line, the foam will be a dry insulation in winter and wet in summer, heat conductor in summer (gradient inwards) and as such it will dissipate heat better than dry [37].

The Need for a National Program for Residential Buildings Renewal

Main criteria for an assessment of the building's value are productivity and well-being of the occupants, while energy or environment are difficult to quantify. Still, when we stress one aspect out of many, we give the impression of unbalanced technology. Medows said that grants, tax reductions, and sponsorships do not have impact on sustainable built environments while the highest social value like climate change has an unquestionably high impact [38]. Why are we not using it? The answer is simple; the global market is nobody's market. We have managed to break society's values in quest for money, today we must use different means for rebuilding local socio-economic values. For instance, when visiting Building Physics group at one Montreal University, I asked questions and no one knew about the Rosemount project. When asked by the city archives where the first passive house was built, they had neither a picture nor an idea about such a building. Without the involvement of the academics, there was no champion talking about the benefits of the project. The people who want to introduce ecological construction and have no economic knowledge are doing money giveaway instead creating the "market pull". Years ago, we had all technology transfer channels, and other tools, but because of elimination of technology transfer and funding academic projects without the follow up to marketplace, we have lost the cohesion between academic and industrial world. The epidemics deleted the old order, sponsoring products on the market does not create market forces. Tools alone, even as sophisticated as AI, are only tools used like hammer to drive nails. Unless the use of technology is synchronized with the social awareness of ways to slow climate change, the latter will never be achieved in practice. In closure, we repeat any technology is one leg only, to walk one needs two and the second leg is a public education. This is needed for public change of thinking paradigm and public-private national demonstration projects are the best way to educate public. An immediate solution should be to use the NA experience and create a national residential building renovation project East European or Asian program like one that we propose for Poland. The Polish proposal is closer to the Canadian R2000 than the US program because we need to create foundation for market spread of PTAC technology. We need to use the taxpayer money to build the missing links enhancing scientific basis for the next generation technology. To this end we are starting with a vision based on the public domain of PTAC technology as the platform for the next generation technology. There are, however, a few patents restricted for private companies who would join the demonstration cases and either expand their market or create a license system. This pilot project is to teach the teachers who want to continue with rapid skills in market development.

Elements of research and demonstration in the proposed project

One must define the limit of performance and the market cost of today's reference buildings. is to have a well-established reference cost

There are two types of reference buildings:

• a low-rise 1 to 3 stories incl. with no more than 70 kWh/(m2a), and
• a mid-rise 4-11 stories, the energy limit is 100 kWh/(m2a)
• A critical area of consideration is selection of the monitoring components of MAPE, to allow separating energy carried by air flow from that by conduction through the building enclosure. Thus, we use west and north side of the building, to measure temperature and air pressure difference between indoor and outdoor environments, as well as air pressure difference between the monitored dwelling on top and entrance levels and at the neutral pressure plane [39].
• The role of air pressure differences will be better understood in context of broad research on control of air flows (energy, durability, IAQ).
• PTAC technology deals with interior applications when exterior insulation has already been added, still, if a building needs to have more thermal insulation, one may add a layer of thermal insulation on the interior, resolving increased effects on thermal bridges.
• MAPE modelling requires hourly data collection for all data including the weather,
• As artificial neural network models may have a higher precision [40-44]. One must enforce either co-simulation or calibration of all models if used in real time or for decision-making purposes.
• To increase precision of models, one must also characterize the building type and link the hourly data of energy use with the monitoring and weather data.
• To establish effect of climate and height correction on the average air pressure on the level of analyzed dwelling (distance from neutral air pressure) one must perform monitoring and data collection for one full year.
• The intake of ventilation air from an exterior wall should be designed in such a way that air is protected from ingress of insects and preheated when passing along the exterior wall before entering (preferably a stratified and hybrid) ventilation system. Before the ventilation air enters the dwelling a 2.5-micron filter, and if one intends to dry masonry walls then also a dehumidifier is needed.
• The exhaust of ventilation can be from the bathroom (kitchen has independent exhaust).
• Drying of walls will be better understood in context of broad research on humidity and moisture management (durability, IAQ) in retrofitting technology [45-48].
• The complexity of PTAC functions would be better understood if one separates the whole system into a few sub-systems, namely:
• Heating and cooling units including water sourced heat pump (WSHP), cold water tank (CWT) and domestic hot water (DHW)
• Heat exchangers located in walls, floors or ceiling either made continuously in-situ or mounted in panels with snap-on connections [30].
• Automatic distribution system with water pumps to the heat exchangers and the next building
• Software operating the energy and ventilation distribution systems
• Establishing holistic and balanced approach and a few schematic drawings about retrofitting for teaching building physics

Concluding Remarks

The boom after WWII was possible because we used traditional technology. Nevertheless, When the tradition became slowly replaced by new ecological demands, there was nobody to create a new vision because of market fragmentation in construction and absence of national research centers. To create a public vision, we need to create a socio-economic wave around a new thinking paradigm, requesting the next generation of retrofitting technology to slow the rate of climate change. This is a technological revolution [1]. That will have three beneficial aspects: for ecology by slowing climate change, for economy by creating many local jobs, and for building occupants by improving an affordable comfort [49,50].

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