© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

C64

Numerical Analysis of Energy Retrofits Impacts on Indoor Thermal and Air Quality of Single-Family Houses

Marc Abadie, PhD **Charles-Florian Picard, PhD** **Jérôme Nicolle, PhD**

Bénédicte Wall-Ribot, PhD **Kátia Cordeiro Mendonça, PhD**

ABSTRACT

In building energy renovation, the notion of payback time is often presented as the only goal i.e. it is important to demonstrate that energy savings can rapidly reimburse the investments made to generate them. However, the notion of comfort gain, as well as the potential benefits in terms of health, are also important and should be accounted for. This paper presents the results of the French research project Smart-Réno-IEQ (2019-2021) that aimed at analyzing the impacts of energy retrofits on indoor thermal and air quality of single-family houses. Based on an analysis of the existing building stock (construction year, envelope composition, heating system, infiltration and ventilation rates…) and retrofitting actions done in recent years (window replacement, increasing the wall/roof insulation, changing the heating/ventilation systems…), a set of single and multiple renovation actions have been defined to assess the performance of the renovation in terms of thermal comfort and Indoor Air Quality (IAQ). The different configurations have been modelled accounting for heat and mass (air and pollutants) transfers in multizone houses during the whole year. A new indicator, based on existing indices, has been defined to evaluate both thermal comfort and IAQ for each season, year and overall to assess the benefits of retrofitting. Results show that effects on thermal comfort such as replacement of windows, thermal insulation of vertical walls or attics are negligible even if they are essential for energy consumption reduction. Only actions of limiting indoor sources of pollutants and upgrading ventilation have noticeable positive effects on IAQ and positive or negative ones on thermal comfort. Another finding in line with energy performance efficiency is that packages of renovation actions are always more beneficial for IAQ than isolated actions.

INTRODUCTION

Energy retrofits in buildings are primarily assessed based on their ability to reduce energy consumption and generate financial savings. Payback time is often considered the key metric to justify renovation investments. However, real-world outcomes frequently fall short of expectations, with projected savings rarely met or exceeded. This discrepancy arises from various factors, including technical biases in estimating initial conditions and unaccounted operational inefficiencies. Additionally, occupant behavior plays a critical role, as seen in the rebound effect: residents in energy-efficient homes may choose to increase their heating comfort rather than maximize energy savings. While this effect challenges policy-driven energy savings projections, it highlights the perceived value of improved indoor comfort and its importance in renovation decisions.

Beyond energy savings, renovations significantly influence indoor environmental quality, particularly thermal comfort and indoor air quality (IAQ). Comfort is a multidimensional concept encompassing thermal, hygrothermal, acoustic, visual and

Marc Abadie is an associate professor within the Department of Civil Engineering and researcher at LaSIE (CNRS UMR 7356), University of La Rochelle. **Charles-Florian Picard** is a project manager at TIPEE, Lagord (FR). **Jérôme Nicolle** is a laboratory manager at TIPEE, Lagord (FR). **Bénédicte Wall-Ribot** is an expert research engineer at EDF, Écuelles (FR). **Kátia Cordeiro Mendonça** is a Projects and R&D Manager at TIPEE, Lagord (FR). Marc Abadie and Bénédicte Wall-Ribot are also members of 4evLab (EDF R&D/LaSIE common Laboratory) and Marc Abadie, Charles-Florian Picard, Jérôme Nicolle and Kátia Cordeiro Mendonça are also members of RUPEE Lab (TIPEE/LaSIE common Laboratory).

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

air quality aspects, with some factors being consciously perceived by occupants while others, such as pollutant exposure, remaining undetected although impacting health. Assessing these effects requires quantifiable indicators that reflect the actual benefits of retrofitting beyond energy efficiency alone.

This paper presents findings from the French research project Smart-Réno-IEQ (2019-2021), which analyzed the impacts of energy retrofits on indoor thermal and air quality in single-family houses. The study first characterizes the existing building stock and common retrofit actions, such as window replacement, insulation upgrades, and heating or ventilation system improvements. Using a multizone modeling approach, the project evaluates heat and mass (air and pollutant) transfers over a full year for various renovation scenarios. A new composite indicator, derived from existing indices, has been developed to assess both thermal comfort and IAQ across seasons and over time, providing a holistic measure of the retrofit performance.

The paper first outlines the methodological framework of the Smart-Réno-IEQ project, followed by an analysis of the main results from the numerical simulations. The discussion highlights key insights into how different renovation strategies impact indoor thermal and air quality, offering a more comprehensive perspective on the benefits of energy retrofits in residential buildings.

METHODS

This study investigates the thermal and IAQ implications of energy retrofits in single-family houses, focusing on three representative building types based on French housing stock analysis.

Description of Representative Building Types

An analysis of the existing building stock has been done to identify its main characteristics (envelope composition, heating system, infiltration and ventilation rates…) according to the building construction year. Figure 1 illustrates the effect of the successive national thermal regulations on the reduction of the overall heat transfer coefficient (U) for all parts of the building envelope. It also illustrates the decrease of the infiltration rate (q_{4Pa}), particularly in the last three decades. According to this Figure 1, the average size of the French houses (floor surface area A) was below 100 m^2 (1076 ft^2) before the 1980's, strongly increased in the 1990's and is nowadays stabilized around 120 m^2 (1292 ft^2).

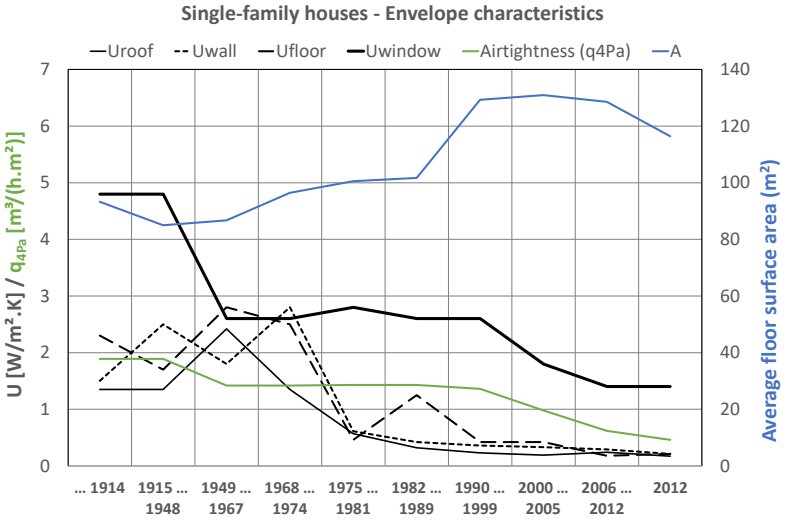

Figure 1 Historical evolution of French single-family houses envelope characteristics.

Three categories of houses were selected to represent the most common renovation challenges encountered in the residential sector (Figure 2):

- Case 1: Pre-1948 houses, F-rated French energy label with C-rated objective after renovations, characterized by poor insulation, high air infiltration rates, undersized heating system and no ventilation system (air renewal is

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

ensured through infiltration across the building envelope).

- Case 2: 1948-1974 houses, F-rated French energy label with C-rated objective after renovations, with minimal insulation, intermediate air infiltration rates, basic heating systems and natural ventilation by ducts (air renewal is ensured by combined thermal draft and wind with air inlets (grilles) located on façade and extraction ducts in service rooms).
- Case 3: Post-1974 houses, D-rated French energy label with B-rated objective after renovations, with moderate insulation, improved airtightness, well-sized heating systems and pressure-controlled exhaust ventilation (a mechanical ventilation system with extraction fan where the air inlets and extraction vents are self-regulated based on pressure to maintain a constant airflow regardless of external conditions).

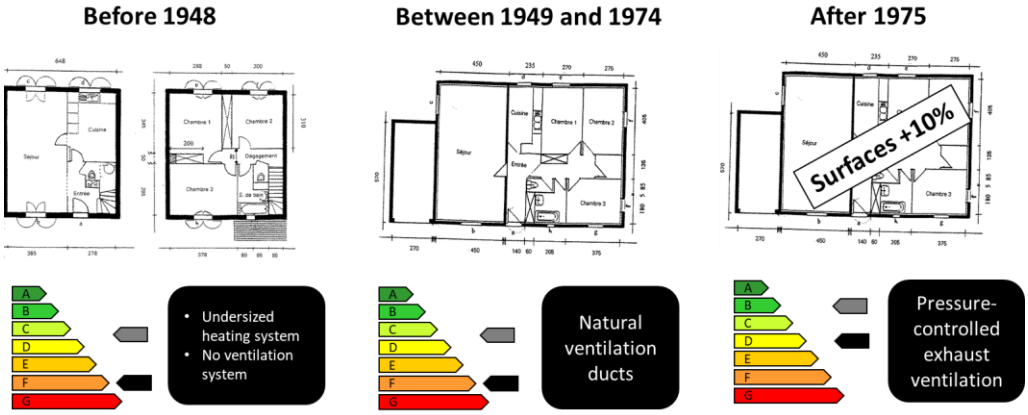

Figure 2 Selected categories of houses.

Retrofit Scenarios

To identify the renovation actions held in France in the last decade, we compiled data from different databases and literature reviews (OPEN, 2016; TREMI, 2018; Rochard et al, 2015) in one graph (Figure 3). This figure shows the main renovation actions held in the 2014-2016 period along with the identification of the renovated building construction year (pie chart) and the key elements defining standard and high-performance retrofits in France. A total of 12 million retrofit actions have been performed during this two-year period: 23% of window replacement, 20% (roof) + 18% (walls) of insulation improvement and 17% of heating system renewal. The three other actions represent only 9%, 7% and 5%, respectively.

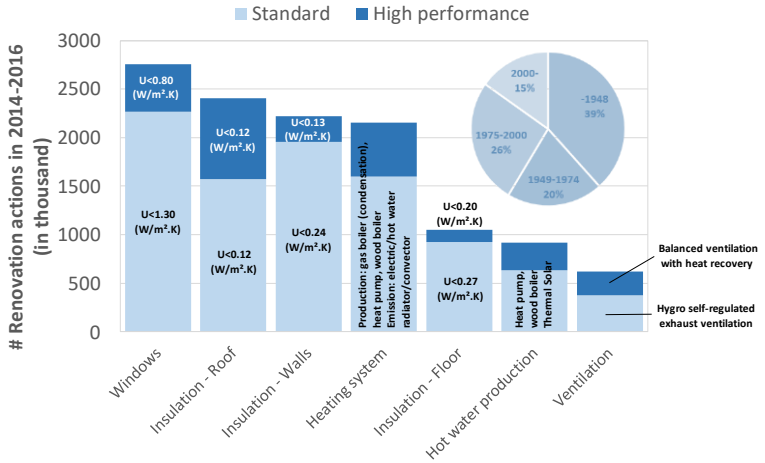

Figure 3 Renovation actions in French single-family houses in 2014-2016.

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

For this study, the following retrofit strategies were considered: #1 – Window replacement (improved thermal performance U_{window} = 1.30 W/(m².K) and airtightness Q_4 = 1.3 (m³/h)/m²)), #2 – External wall insulation (U_{wall} = 0.2 W/(m².K)), #3 – Attic insulation (U_{roof} = 0.12 W/(m².K)), #4 – Indoor decoration renovation (decoration + finishes), #5 – Upgrade to hygro self-regulated mechanical ventilation (or humidity-controlled ventilation designed to optimize air renewal by increasing airflow when humidity rises and reducing it when humidity is low), #6 – Renovation package (combining all measures but ventilation) and #7 – Renovation package (combining all measures). Note that actions #1 to #3 improve the envelope thermal performance and airtightness. Action #4 lowers VOC indoor sources. Action #5 has different consequences on air renewal: it increases the airflow rates compared to the oldest houses with no ventilation system, reduces the whole house air renewal compared to the pressure-controlled exhaust system but modulates it according to air relative humidity (linked to the presence of occupant or occupant activity) in room, and can provide more or less air exchanges with outdoor compared to the natural ventilation ducts system.

Simulation

A multizone modeling approach considering each room separately has been performed for heat and mass (air and pollutant) transfers over a full year for a total of 216 configurations: 3 construction periods (Case 1, 2 and 3) × 3 geographical locations (cold, intermediate/oceanic and mediterranean climate zone) × 3 pollution levels (urban, suburban and rural) × 8 energy levels (Initial state + 7 retrofit actions). Two simulation environments, BuildSysPro (Sayegh et al., 2023) and TRNSYS -CONTAM coupling (Klein et al., 2017; Dols and Polidoro, 2015), were used to perform all numerical simulations regarding Case 3 located in a cold climate zone with urban pollution level. Despite a very precise set of specifications, the predicted values from the two environments show some differences, but their impact on the calculation of comfort and indoor air quality (IAQ) indicators remains minimal. Simulation results from TRNSYS-CONTAM coupling are presented in this paper.

Each numerical simulation was carried out over a year with a simulation time step of 10 minutes. The output variables concerned air temperatures and relative humidity, average operating and radiant temperatures, wall surface temperatures, heating requirements, relative pressures, air exchange rates and concentrations of $PM_{2.5}$, NO_2, benzene, toluene, formaldehyde and CO_2. All these variables have been saved for all the rooms in the homes studied every 30 minutes.

Note that all indoor sources of heat (body production, cooking, showering and electrical equipment), moisture (respiration, cooking, washing, showering) and pollutants (from occupants, envelope materials, decoration products, furniture and cooking) have been set identical for all cases studied (Wall-Ribot et al., 2021). Moisture buffer effects were also evaluated for each room considering the interactions between water vapor in air and the first layer of floor/vertical walls/ceiling materials. $PM_{2.5}$ and NO_2 interactions with indoor surfaces have been considered with the deposition velocity approach; no sorption effect was accounted regarding VOCs. All interior doors and windows were kept closed during the entire simulation period. No solar shading was accounted in the simulations.

Thermal comfort and IAQ Indicators

From the variables obtained by simulation, a set of sub-indicators related to hygrothermal comfort and IAQ has been selected to evaluate the effects of renovation actions.

Four thermal comfort indicators have been calculated considering average values over the considered periods. We assumed constant values for clothing factor (1 CLO), metabolic rate (1 MET) and air velocity of 0.1 m/s. The indicators are:

- PPD (Fanger, 1970): the PMV (Predicted Mean Vote) is used to calculate the thermal sensation felt by occupants under environmental conditions (air and radiant temperatures, relative humidity, etc.) that are stable over time, i.e. in air-conditioned environments. In our case, this indicator can therefore be used during the heating period only. The PPD (Predicted Percentage of Dissatisfied) translates the percentage of dissatisfied people from the PMV (discomfort) and varies from 5 to 100%.
- PPD^*: it's an adaptation of the PMV-PPD that includes greater sensitivity to high relative humidities, but above all considers the human body's response to a dynamic variation in environmental conditions (Gagge et al., 1971; Gagge 1973; Gagge, 1986). This indicator can therefore be used outside the heating season (spring and fall in our case). PPD* also varies from 5 to 100%.
- $DH_{discomfort}$ (Degrees-hour of discomfort): this is calculated as a function of the optimal straight line given by the principle of adaptive comfort (de Dear and Brager, 1998), which considers the adaptability of occupants to indoor

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

conditions in relation to outdoor temperature levels. It can therefore be used to quantify summer thermal discomfort and is not bounded, since it represents the accumulation of the deviation of the indoor temperature from the optimum temperature over a given period.

- $PPD_{radiant\ asymmetry}$: it is a criterion for assessing the discomfort induced by a cold or hot wall in an indoor environment (ISO 7730, 2005). This discomfort is expressed in PPD and varies from 0 to 100% and is used for all periods.

Two IAQ indicators have been considered in this study:

- ULR-QAI (Cony Renaud-Salis, 2019): this is a multi-pollutant indoor air pollution indicator based on the average concentration of each pollutant over a given period using Exposure Limit Values (ELV) defined by ANSES (2018) in France. Its scale ranges from 0 (limited pollution with all pollutant average concentrations below long-term ELV) to 10 (with at least one pollutant with average concentration above short-term ELV).
- DALY (Logue et al., 2011): DALY (Disability Adjusted Life Years) is an indicator quantifying the number of years of healthy life lost due to exposure to pollutants. Its scale is not bounded, since it depends on the concentration levels of the pollutants considered.

Smart-Réno Indicators

The Smart-Réno Index is designed to evaluate the effects of renovation actions on hygrothermal comfort and indoor air quality (IAQ).

Normalization of Sub-Indicators. The six previously defined indicators need to be aggregated to obtain annual comfort and IAQ sub-indicators from seasonal results and, ultimately, a single indicator (the Smart-Réno indicator) that characterizes both comfort and IAQ. Therefore, it is essential to ensure that all sub-indicators are expressed on the same scale.

The three thermal comfort sub-indicators: PPD, PPD*, and $PPD_{radiant\ asymmetry}$, already share the same scale. Regarding $DH_{inconfort}$, we propose normalizing it based on the French standard RE2020 criteria (CEREMA, 2024), which sets the discomfort degree-hours threshold to 1250°C.h for single-family homes. It will be expressed as a percentage of this value. The thermal comfort sub-indicator for a considered period is then the highest calculated sub-indicators (worst-case) e.g. it will be the maximal value between PPD and $PPD_{radiant\ asymmetry}$ in winter.

ULR-QAI, which ranges from 0 to 10, will be divided by 10 and expressed as a percentage (Cony Renaud-Salis et al., 2019).

Finally, the normalization of DALY is more complex. DALY normalization anchors to $PM_{2.5}$ health impacts, where: $DALY(GV_{LT-PM2.5}) = 750$ is the health burden at WHO long-term exposure limit (10 µg/m³) and $DALY(GV_{ST-PM2.5}) = 1500$ is the health burden at WHO short-term limit (25 µg/m³)[1]. These values derive from epidemiological studies linking $PM_{2.5}$ concentrations to life-years lost (Logue et al., 2011):

$$DALY_{norm} = \frac{DALY_{original} - DALY(GV_{LT-PM2.5})}{DALY(GV_{ST-PM2.5}) - DALY(GV_{LT-PM2.5})} = \frac{DALY_{original} - 750}{1500 - 750} \quad (1)$$

For example, if a simulation yields DALY = 1125 for a retrofit scenario, the normalization leads to 50% i.e. the scenario's health impact is midway between "safe" (LT-ELV) and "hazardous" (ST-ELV) thresholds.

The index accounts for both annual and seasonal variations since some thermal comfort sub-indicators are only relevant under specific environmental conditions. The bedrooms and living room are analyzed based on the space-time budget approach, assuming a 24/7 occupant: bedrooms are considered for nighttime and living room is used for daytime. Since these sub-indicators represent discomfort and pollution with higher values indicating worse conditions, they are inverted in the final calculations to facilitate the understanding: final values = 100% - initial percentage, ensuring 100% represents optimal comfort and IAQ.

Final Representation. Figure 3 presents the final representation of the evaluation of hygrothermal comfort and Indoor Air Quality (IAQ) for a given energy situation. A simple color code is used: red (0%) represents the worst conditions, while green (100%) indicates optimal comfort and IAQ.

[1] The values used in this work are the ELV defined by WHO before 2021 i.e. 10 µg/m³ and 25 µg/m³ for long- and short-term periods respectively.

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

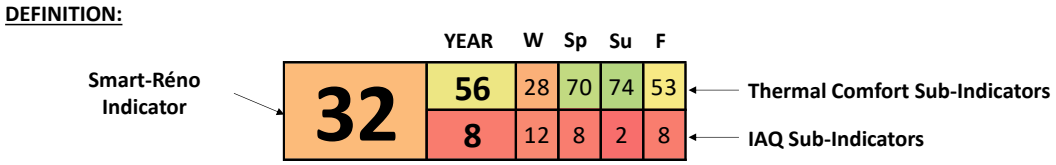

Figure 3 Final representation of the Smart-Réno Index. Columns: Periods (Year, **W**inter, **S**pring, **S**ummer and **F**all). Scores combine thermal comfort (top) and IAQ (bottom) sub-indices.

The Smart-Réno indicator (first box on the left) represents the overall score, combining comfort and IAQ assessments.

The issue of aggregating sub-indicators (such as comfort and IAQ) was studied by Abadie and Wargocki (2017), who concluded that the lowest sub-indicator value should be used as the global indicator to avoid downplaying severe unfavorable situations. However, the Smart-Réno study has a different context, as it aims to compare pre- and post-renovation situations that are not extreme in terms of thermal comfort or IAQ. To better highlight the effects of renovation actions, the Smart-Réno indicator is based on the annual average of the thermal comfort and IAQ sub-indicators.

These two annual sub-indicators (thermal comfort and IAQ) are also displayed in the second column, with comfort at the top and IAQ at the bottom. Each annual score (YEAR column in Figure 3) is calculated as the seasonal average for comfort and IAQ (shown in the following columns with "W" for Winter, "Sp" for Spring, "Su" for Summer and "F" for Fall).

The example in Figure 3 illustrates a case with an overall score of 32/100, which corresponds to the average of the hygrothermal comfort score (56/100) and the IAQ score (8/100). The greatest discomfort occurs in winter, with a score of 28/100. Comfort is very good in spring (70/100) and summer (74/100), while it is only moderate in fall (53/100). IAQ remains poor throughout the year, with scores of 12/100 in winter, 8/100 in spring, 2/100 in summer, and 8/100 in fall.

RESULTS

Smart-Réno dashboard

Figure 4 presents the Smart-Réno dashboard used to analyze the effect of energy retrofit actions on thermal comfort and IAQ. The case presented here concerns houses built before 1948, located in climate zone H1(cold) and in an urban environment. Before renovation (#0), the evaluation gives 34/100 considering both thermal comfort and IAQ that comes from scores of 53/100 for thermal comfort and only 15/100 for IAQ. As the heating system is slightly undersized in this case, the score during winter is only 40/100. For spring and fall, because of the poor envelope insulation and no heating, thermal comfort is 40/100 and only 26/100, respectively. However, thermal comfort is optimal during summer. IAQ is better during winter because of indoor to outdoor temperature gradient that allows higher infiltrations through the envelope, inducing lower VOC concentrations. IAQ is worsen for other seasons with the lowest score of 5/100 during summer because of very low air renewal.

The goal of this paper being the presentation of the methodology applied to evaluate the effects of energy retrofits on thermal comfort and IAQ, we will not explain all the details that comes out from Figure 4 as it really depends on the simulation parameters regarding the houses' geometries, thermal properties, heating system and control… However, the following general trends can be easily observed with the Smart-Réno dashboard:

- All renovation actions have impacts on both thermal comfort and IAQ except for #4 that has no effect on thermal comfort as it concerns only a reduction of indoor sources of VOC.
- Action #3 (Attic insulation) alone has not the best effect on thermal comfort (#2 is better) but the worst effect on IAQ as it lowers the air renewal through the envelope by infiltration.
- Action #5 (adding a ventilation system) alone provides the best air quality (+46) but worsen the most the thermal comfort (with identical heating system).
- Packages of actions #6 and #7 are the best solutions with Smart-Réno indicator increasing of +20 and +25, respectively. However, if we look at details, those two solutions are quite different as #6 improves thermal comfort (except for summer with a small penalty) and IAQ and #7 essentially worsen thermal comfort for 10 points while improving drastically IAQ (+59).

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

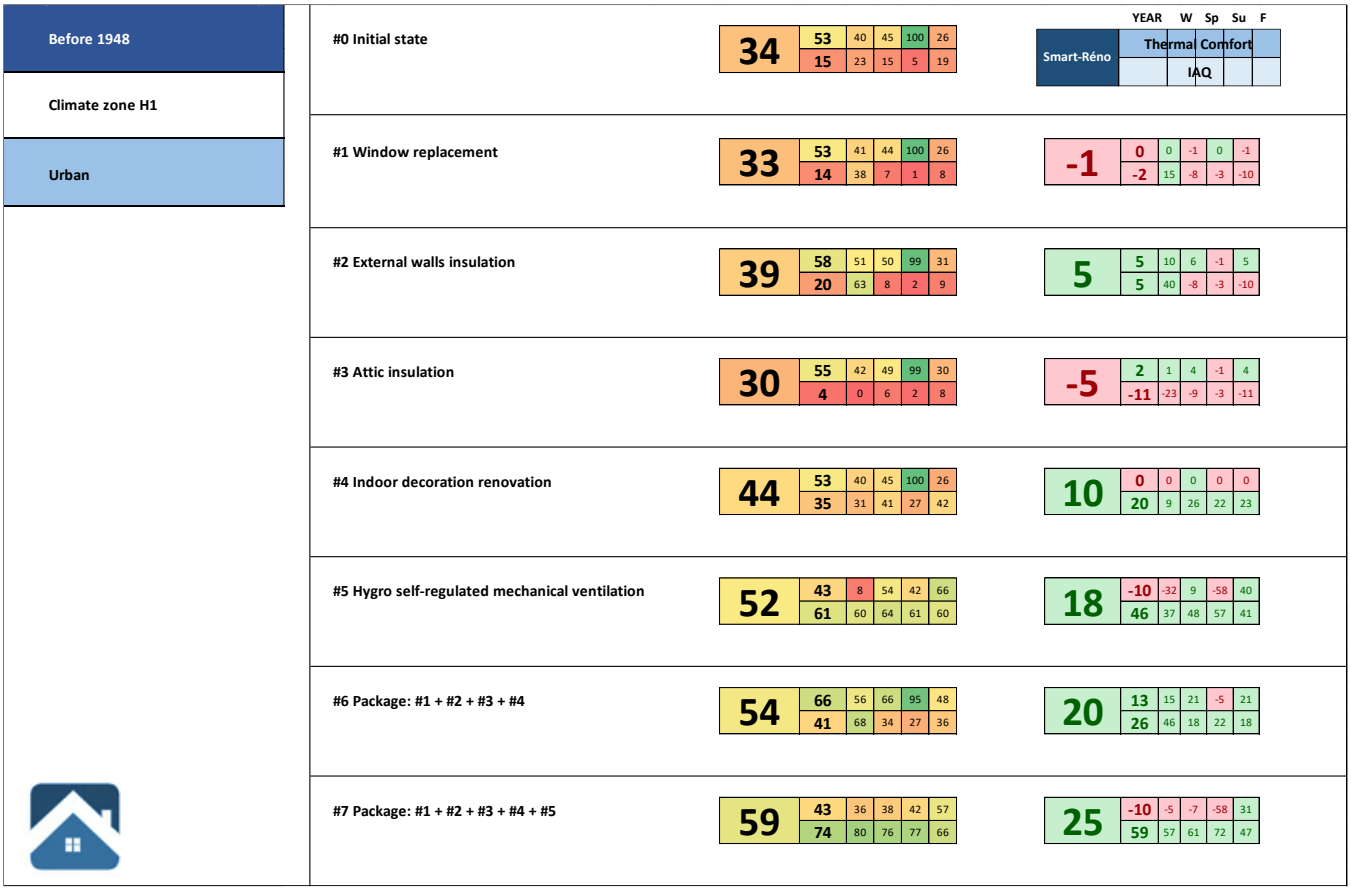

Figure 4 Smart-Réno dashboard for pre-1948 homes in cold urban climates. Rows: Retrofit actions (#0–#7). Columns: Seasons (Winter–Fall). Colors: Red (0%) = poor, Green (100%) = optimal. Scores combine thermal comfort (top) and IAQ (bottom). The Smart-Réno indicators on the left-hand side display absolute scores, while those on the right-hand side show the benefits (in green) or drawbacks (in red) of the action relative to the reference case.

Overall results

Figure 5 compiles all results altogether. The thermal comfort/IAQ level of houses in their initial state corresponds to their year of construction, with older houses having poorer indoor conditions than newer ones. It can also be seen that renovation actions have a greater impact (particularly positive) on older homes.

As might be expected, exterior modifications to the envelope (actions #1 to #3) have a negligible effect on the indoor conditions as observed in Figure 4. We note a slight deterioration in the indicator induced by the reduction in the air permeability of the envelope, and therefore in the air renewal of the dwelling, for houses built before 1975, which do not have mechanical ventilation capable of compensating for air flows. Action #4 limits indoor sources considerably and improves IAQ, which depends solely on outdoor pollution when indoor source strengths are reduced. Installing mechanical ventilation has the most effect for the oldest houses initially without a ventilation system, and an effect equivalent to trapping indoor sources for houses built between 1949 and 1974. However, a high negative effect is observed for the most recent houses, which go from a pressure- to a humidity- controlled system; lower flow rates in the presence of significant indoor sources explain this result.

Packages combining renovation actions with or without ventilation therefore have a positive effect compared with the

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

initial state of all houses. We note that it is the complete package of actions (#7) that remains the most favorable for pre-1975 houses. However, the maximum achieved by the most recent houses cannot be reached by the oldest houses for similar renovation actions. Finally, geographical location in terms of climatic conditions has more impact on older houses indoor conditions.

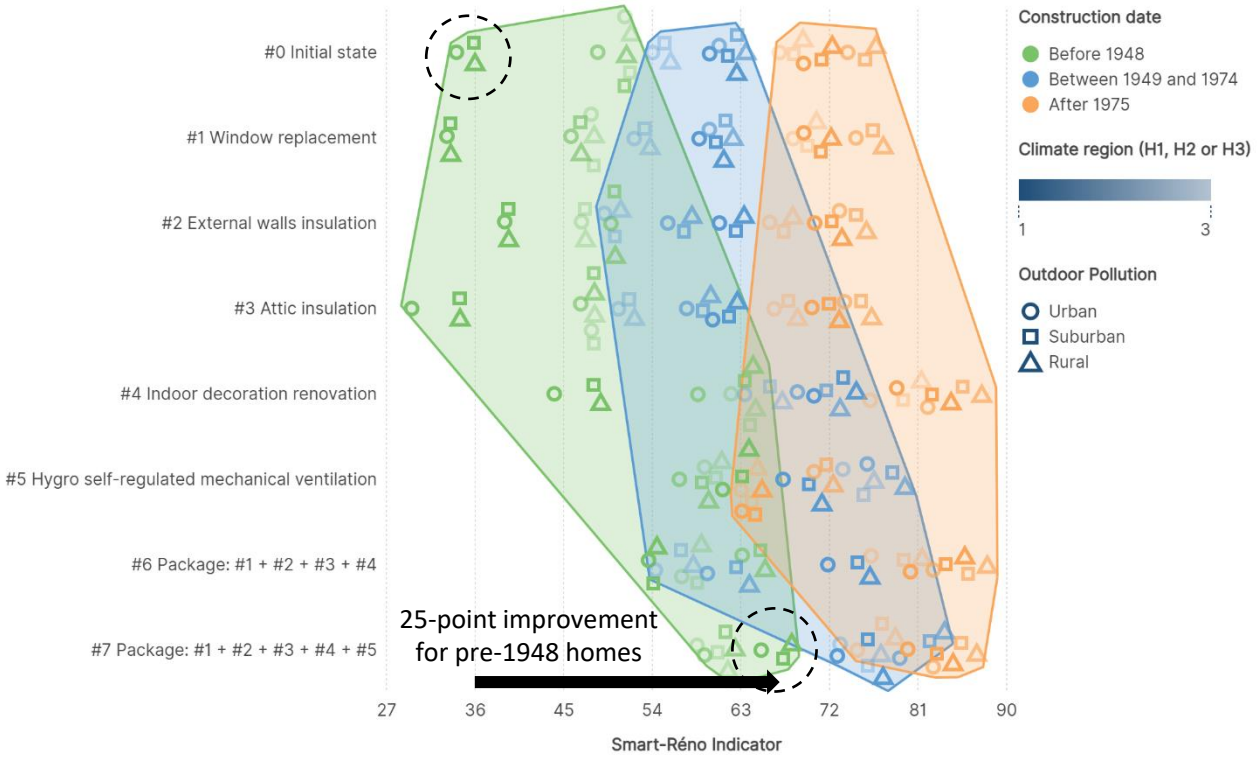

Figure 5 Smart-Réno scores by building construction period (Pre-1948 to Post-1974). X-axis: Score (0–100%). Y-axis: Reference case and renovation actions. Trend: Older homes show larger gains from packages (#6–7) due to baseline deficiencies in insulation/ventilation.".

CONCLUSION

This paper summarizes, through the calculation of the overall Smart-Réno indicator and its sub-indicators, the results of numerical simulations carried out to analyze the effects of renovation actions on thermal comfort and IAQ as a function of building age and geographical location in terms of climate zone and outdoor air pollution.

For France's MaPrimeRénov' program, our results suggest subsidies should require bundled retrofits (e.g., insulation + ventilation) to prevent IAQ degradation. For example, Action #7 (full package) boosts IAQ by 59 points in pre-1948 homes, whereas isolated insulation (#3) worsens IAQ by reducing infiltration. Also, codes could mandate low-VOC materials (Action #4) in energy retrofits, as standalone insulation (#1–3) has negligible comfort/IAQ impacts.

It should be noted, however, that while these overall results do provide a general trend for all the cases considered, they should be treated with caution, and it is preferable to refer to each case independently of the others to draw the right conclusions. We have seen, for example, that switching to humidity-sensitive mechanical ventilation was beneficial for cases initially without mechanical ventilation systems, but detrimental for cases with an adequate mechanical system.

© 2025 ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

ACKNOWLEDGMENTS

Smart-Reno is one of the Innovation programs in favor of energy demand management funded by the French Ministry of Ecological and Solidarity Transition.

REFERENCES

Abadie M.O., Wargocki P. 2017. IEA EBC Annex 68, IAQ - indoor air quality, IAQ metrics. AIVC Contributed Report 17, 116p.

ANSES 2018. Liste des Valeurs guides de qualité d'air intérieur de l'Anses (www.anses.fr/fr/system/files/Tableau_VGAI_Juillet%202018.pdf).

CEREMA. 2024. Guide RE2020 : Eco-Construire Pour Le Confort De Tous, Tech. Rep., pp. 1–72, (https://www.ecologie.gouv.fr/sites/default/files/documents/guide_re2020_version_janvier_2024.pdf).

Cony Renaud-Salis L., Ramalho O., Abadie M. 2019. Towards the definition of an indoor air quality index for residential buildings based on long-and short-term exposure limit values. International journal of ventilation 19, 189–200.

De Dear R.J., Brager G.S. , 1998. Developing an adaptive model to thermal comfort and preference. ASHRAE transactions, 1998, vol. 104, Part 1A, pp. 145-167.

Dols W.S., Polidoro BJ. 2015. CONTAM user guide and program documentation, version 3.2. Technical Note (NIST TN) – 1887, National Institute of Standards and Technology, U.S. Department of Commerce, 331 p.

Fanger, P. O. 1970. Thermal comfort. Copenhagen, Denmark: Danish Technical Press 244 p.

Gagge A.P, Stolwijk J.A, Nishi Y. 1971. An effective temperature scale based on a simple model of human physiological regulatory response. ASHRAE Transactions, 77, pp. 247-257.

Gagge A.P. 1973. Rational indices of man's thermal environment and their use with a 2-node model of his temperature regulation. Fed. Proc., 32, 1572-1982.

Gagge A.P. 1986. A standard predictive index of human response to the thermal environment. ASHRAE transactions, vol. 92, Part 2B, pp. 709-731.

ISO 7730. 2005. Ergonomie des ambiances thermiques — Détermination analytique et interprétation du confort thermique par le calcul des indices PMV et PPD et par des critères de confort thermique local.

Klein S.A. et al. 2017. TRNSYS 18: A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA, http://sel.me.wisc.edu/trnsys .

Logue J.M., Price P.N., Sherman M.H., Singer B.C. 2011. A Method to Estimate the Chronic Health Impact of Air Pollutants in U.S. Residences. Environmental Health Perspectives, 120 (2), 216–222.

OPEN. 2016. Enquête – Campagne 2015: Travaux achevés en 2014 – Observatoire Permanent de l'amélioration ENergétique du logement. Report, ISBN 979-10-297-0289-1, 31p.

Sayegh H., Duforestel T., Bouia H., Wall-Ribot B., Labbe S., Covalet D., Charrier B. 2023. Indoor air quality (iaq) in the ibpsa modelica library (part ii): Methodology of integration of new iaq simulation models. 18th International IBPSA Conference & Exhibition.

Smart-Réno. 2020. https://smart-reno.recherche.univ-lr.fr/

Rochard U., Shanthirablan S., Brejon C., Chateau Le Bras M. 2015. Typologie du parc existant et solutions exemplaires pour la rénovation énergétique en France. Report, EPISCOPE project, IEE/12/695/SI2.644739, April 2013 – March 2016.

TREMI. 2018. Enquête – Campagne 2017 : Travaux de Rénovation Energétique des Maisons Individuelles. Report, ISBN 979-10-297-1023-0, 32p.

Wall-Ribot B., Covalet D., Forget B., Abadie M., Picard C.-F. 2021. T3.4 – Mise en œuvre de la méthodologie proposée par simulations - Cahier des Charges. Technical report of Smart-Réno project, 8 p. https://smart-reno.univ-lr.fr/wp-content/uploads/2022/01/T3.4-Mise-en-oeuvre-de-la-methodologie-proposee-par-simulations.pdf