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Numerical test bench to evaluate the influence of heat gains on the estimation of Heat Transfer Coefficient under occupied conditions

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Abstract. The estimation of the HTC heat transfer coefficient in real occupancy conditions has a great operational advantage contrary to the measurement in unoccupied conditions, which requires specific measurement protocols. Nevertheless, it presents additional constraints because the gains due to weather conditions and occupancy are poorly controlled. The objective of this work is therefore to quantify the impact of these different gains. A numerical test bench is set up to study the impact of the solar and internal gains by varying different parameters, such as the typology of the building, the meteorological conditions, the scenarios of occupancy. These numerical tests allow to estimate the HTC of a building by calibrating a numerical model from a virtual dataset generated by a detailed model with known and controlled meteorological conditions and usage conditions. They make it possible to determine the share of solar heat gain and internal heat gain in the energy balance of the building and their impact on the estimation of the HTC according to the studied configurations.

Keywords: performance evaluation, HTC estimation, occupancy, solar gains

1. Introduction

Measuring the actual consumption and energy performance of renovated or new buildings is a major challenge in order to reach the objectives set by the European Commission to achieve carbon neutrality of the building stock by 2050. With the evolution of thermal regulations, the energy performance of new buildings has been greatly improved. Nevertheless, there is often a significant gap between the actual consumption of a building and the one planned in the design [1]. It is therefore essential to measure the actual performance in order to understand the origin of the discrepancies and to reach the objectives set in terms of energy savings.

The Heat Transfer Coefficient (HTC) is an indicator that characterizes the thermal performance of a building envelope. Different methods have been developed to estimate this coefficient from in situ measurements. These methods are classified in two categories according to whether the measurements are made in the presence of the occupants or in their absence. In the absence of the occupants, several methods allow to obtain satisfactory results for the estimation of the HTC, such as the co-heating test [2], the QUB method (Quick U-value of Buildings) [3], ISABELE [4] or the SEREINE method



(Solution d'Evaluation de la pErformance Energétique INtrinsèque) [5]. Nevertheless, specific conditions during the realization of the measurements make it impossible to occupy the building.

The estimation of the HTC under real occupancy conditions has therefore a big operational advantage compared to the unoccupied methods. Nevertheless, it presents additional constraints because the gains due to the meteorological conditions and the occupation are poorly controlled. In order to overcome these constraints, measurements over longer periods are necessary. The energy signature method allows to estimate a global HTC in use, corresponding to the HTC plus a variable part due to the uses. This estimation of the HTC of a building in use is done with the help of a heat balance and measurements collected without intrusive instrumentation for the occupants. The PRISM method, developed by [6], is a typical example of an energy signature model. This method allows to have a first estimation of the heat loss coefficient. However, this model should be used with caution for the physical interpretation of the building parameters because it does not allow the disaggregation of the different sources of heat input or heat output. Other methods have been developed, such as the averaging method, the use of linear regression, or the use of ARX or RC models [7], [8], [9]. In [10], the authors evaluate the data analysis capability of the first four models mentioned above (energy signature, average, linear regression and ARX) to identify the heat transfer coefficient. This study shows that, with simulated winter data of 26 weeks duration, the ARX model gives a good estimate of the HTC with a deviation from the reference value that does not exceed 5%. Concerning the linear regression model, the uncertainty of the estimates decreases with the increase of the measurement period. At the end of the 26 weeks, the uncertainty is below 10%. This study therefore shows the relevance of the ARX models, and in a second step of the linear regression models for the estimation of the HTC.

Under Annex 71 work of the International Energy Agency [11], different approaches and models have been compared. Linear regression and dynamic models have shown consistent results. Nevertheless, in the cases considered, the results often show a 20% deviation from the reference value, obtained by co-heating. As a conclusion of these research works, different recommendations are presented, without defining a method or a reference protocol in use conditions. The studies carried out highlight the key elements of the data collection and analysis procedure which will have a strong impact on the estimation of the HTC and which must therefore be considered with caution. Among these elements, particular attention must be paid to the consideration of solar gain, internal gain, infiltration and ventilation as well as the choice of the measurement period.

This literature review seems to indicate that for a sufficiently long time, linear regression will give consistent results for the estimation of the HTC. It has the advantage of simplicity, provided that the solar heat gain, internal heat gain, infiltration and ventilation are better modelled than in the literature. This article proposes to (1) study solar gains and internal loads according to the typology of the building, and (2) quantify their impact on the estimation of the HTC.

2. Methodology

2.1. General overview of the methodology

The methodology developed in this article is based on a numerical test bench as shown in Figure 1. An individual house is modelled under building energy simulation software EnergyPlus and different numerical tests are performed. This test bench will allow, on the one hand, to generate a virtual data set in order to evaluate the capacity of a simplified model to evaluate the HTC by calibration. On the other hand, from the data resulting from the simulation, the heat balance of the building is drawn up for each scenario and the impact of each term of the balance is determined, with a particular attention paid to the solar gains and the internal gains.

2.2. Case study: detached house

The numerical test bench described below is applied on a single house (Figure 2), modelled in EnergyPlus. The geometrical modelling was done with Sketchup 8.

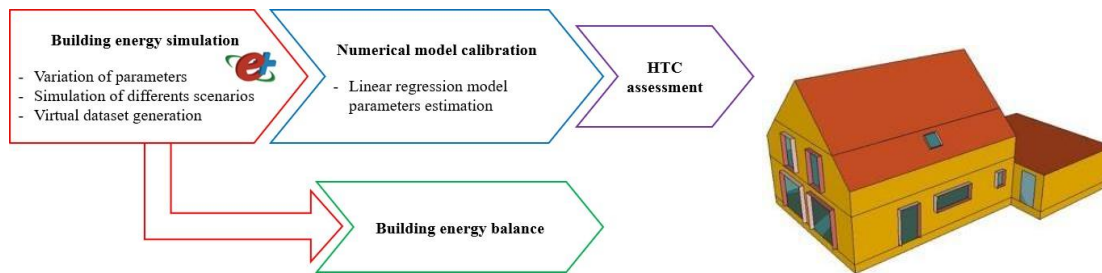


Figure 1. General scheme of methodology. **Figure 2.** 3D modelling of the house: south view.

2.2.1. Envelope description. The house consists of two levels, a crawl space, an attic and a garage. Five thermal zones have been defined under EnergyPlus, but only the first floor and ground floor are considered occupied and are heated. The ground floor, consisting of a living room, a dining room, a kitchen and a bathroom, has a surface of 85m². The first floor, with a surface of 78m², is composed of three bedrooms and a bathroom.

Table 1 explains the composition of the different walls of the thermal envelope of the house, as well as the values of the transmission coefficients U.

Table 1. Compositions and thermal characteristics of the elements of the envelope.

	Exterior walls or against unheated rooms	Floor over crawl space	Attic ceiling	Windows
Walls compositions	Outdoor	Crawl space		
	MI 335: 25cm	Hollow-core slab PSE: 10cm	Attic	Solar factor: 0.45
	PSE: 12cm	PU: 8cm	Stone wool: 40cm	Visible
	Gypsum: 1cm	Concrete screed: 5cm	Indoor	transmittance: 0.56
	Indoor	Indoor		
U (W/m²/K)	0.183	0.186	0.112	1.1

2.2.2. Description of occupancy scenarios. The heating system is modelled in an ideal way to reach the constant heating set points requested. Concerning the mechanical ventilation when it is activated, an air change rate of 90m³/h is introduced permanently, distributed between the two levels in proportion to the surfaces. An additional flow is considered on the ground floor in the kitchen between 7pm and 8pm and corresponds to an increase of 73m³/h. The air infiltrations are considered as constant and fixed at 0,02vol/h. In occupation, a closing of the shutters at night between 7pm and 7am is considered and is applied to all windows at 100% with an additional thermal resistance of 0.15 m².K/W. The internal loads scenarios, presence of the occupants and electrical power dissipated by the domestic activity, were generated in a stochastic way using the AMAPOLA module developed by [12] and then integrated in EnergyPlus. The house is thus equipped with all household appliances and audiovisual electrical devices. The metabolic heat release of the occupants was set to 80W. It is also considered that the consumed electrical powers are entirely dissipated in the ground floor area.

2.3. Definition of the numerical test bench

Since the estimation of the HTC is better during the analysis of winter data, the whole study is carried out over a period of four months from 01/11 to 01/03 for different French weather climates. The numerical test bench varies different parameters of the studied building:

- Typology of the house: 2 insulation levels.
- Weather conditions: 8 weather files.
- Occupancy: the number of occupants which varies from 0, 2, 4 or 6 persons. The rate of presence of the occupants and their energy consumption (12 scenarios).
- Shutter control: permanently closed or open from 7am to 7pm when occupied.

- Heating temperature set point: 19°C, 21°C or 23°C.

- Ventilation: activation of mechanical ventilation or not.

The first test bench aims to study the limits of the linear regression model on its ability to account for solar gain, without occupancy, by varying the weather conditions, the level of insulation, the shutter opening scenario and the heating set point temperatures. The second test bench aims at studying the impact of internal gains and considers different occupancy scenarios by varying the weather files and the heating set points. The two test benches are simulated for the two insulation levels. In total, 312 scenarios are simulated on EnergyPlus.

2.4. Studied weather files

Eight IWEC weather files, representative of French climates, are used for the EnergyPlus simulations. Table 2 compares the meteorological climates in terms of outdoor temperature and solar energy over the period studied.

Table 2. Daily outdoor temperature and average sunshine.

Weather	Daily outdoor temperature (°C)			Global horizontal solar energy (kWh/m ²)
	Maximum	Minimum	Mean	
Bordeaux	19.2	-8.1	7.3	291.3
Brest	16.4	-4.0	7.7	193.7
Clermont-Ferrand	19.5	-12.0	4.7	293.1
Lyon	17.9	-8.3	4.4	198.5
Marseille	19.6	-4.0	8.0	389.0
Nice	19.0	2.0	9.6	411.6
Paris	14.5	-5.5	4.7	181.4
Strasbourg	17.8	-9.7	3.7	221.2

2.5. Numerical models used: data analysis and HTC assessment

The process from the virtual data generated in the dynamic simulations to obtain the HTC is done using 3 linear regression models. These models, which are used to estimate the HTC during co-heating tests, show quite satisfactory results in research works in occupation with long measurement periods [10], [13].

The first model is a heat balance equation modelled for the house, assuming a steady state with a daily time step:

$$\varphi_{heating} + \varphi_{ventilation} + \varphi_{elec} + \varphi_{occupants} + \varphi_{solar} = HTC(Ti - Te) \quad (1)$$

With $\varphi_{heating}$ the heating power, $\varphi_{ventilation}$ the mechanical ventilation gains and losses, φ_{elec} the power of the electrical appliances, $\varphi_{occupants}$ the heat power released by the occupants, φ_{solar} the solar gains through the windows, HTC the heat transfer coefficient and $(Ti - Te)$ the temperature difference between the indoor and outdoor.

The powers of heating, electrical appliances and mechanical ventilation are assumed to be known and correspond to the outputs of the linear regression model. In general, these consumptions can be measured directly or quantities allowing to estimate them can be measured (like the ventilation rate). For this first model, the solar gains and the gains of the occupants are also supposed to be known.

Contrary to the different energy consumptions, the solar gains are more difficult to measure. In the second model, they are assumed to be proportional to the solar irradiation I_{sol} and to an unknown constant coefficient A_{sol} or solar aperture. The heat balance is modelled with equation (2) and the regression analysis minimizes the sum of squared residuals and thus allows the estimation of the model parameters, the HTC and the solar aperture in this case.

$$\varphi_{heating} + \varphi_{ventilation} + \varphi_{elec} + \varphi_{occupants} = HTC(Ti - Te) - A_{sol}I_{sol} \quad (2)$$

Finally, a third model neglects the heat input due to the occupants.

$$\varphi_{heating} + \varphi_{ventilation} + \varphi_{elec} + \varphi_{solar} = HTC(T_i - T_e) \quad (3)$$

Models (2) and (3) are compared to model (1) to study the impact of solar heat gain and occupant heat gain on the HTC assessment.

3. Results

This section presents the results of the numerical test bench conducted on the study case. Among the 312 simulated scenarios, the configurations with a heating setpoint temperature of 21°C are analysed. For the occupied configurations, a scenario with four occupants is arbitrarily chosen among the simulated presence and consumption scenarios.

3.1. Solar heat impact

Figure 3 shows the energy balances performed for each weather climate for the insulated house without occupancy. On the left, the scenarios are simulated with closed shutters and on the right with open shutters during daytime.

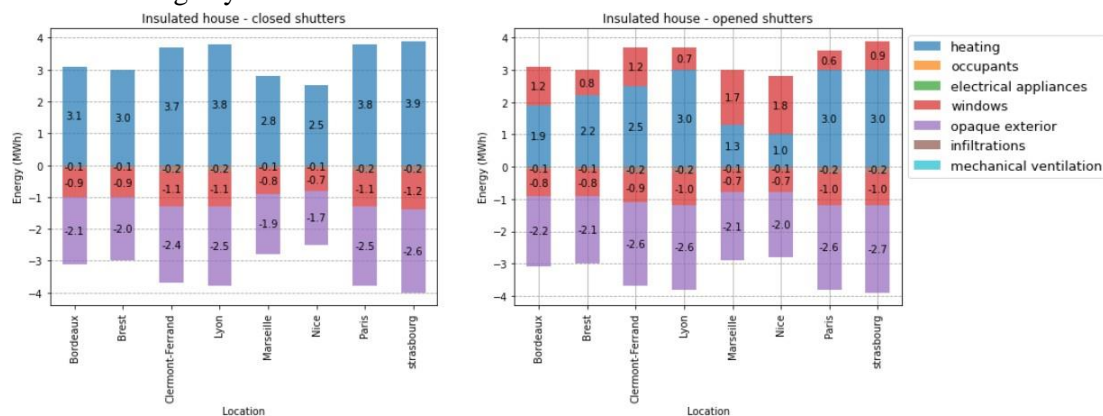


Figure 3. Energy balance – insulated house – closed shutters (left) and opened shutters (right).

The impact of the opening of the shutters and thus of the solar gain entering the house through the windows on the value of the heating power is immediately visible in the energy balances. The impact is all the more important for climates with high sunshine levels, such as Nice or Marseille.

Conversely, Figure 4 shows that, in the case of an uninsulated house, and this, whatever the climate, the solar gains have proportionally less impact on the heating power which is predominant. For a sunny climate, such as Nice, the solar gains through the windows represent only 21% of the heat gains in the non-insulated house, whereas they represent 64% in the case of the insulated house.

HTC is then estimated for these same configurations with the two linear regression models described by equations (1) and (2). Figure 5 shows the HTC values obtained for each weather climate for the unoccupied, unventilated insulated house. On the left the HTC is estimated in closed shutters, and on the right in open shutters. The results of the model calibration corresponding to equation (2) (blue dots on the graph) show a large variability of the HTC for the different climates when the shutters are open compared to the scenarios when they are closed. The higher the solar gains are, the more the results deviate from the target value. When solar gains through windows are considered known (orange dots), the deviation between the model results (1) and the target value is smaller. By comparing the values of HTC with the inputs and outputs of the linear regression model, a dependence of HTC on solar gains is observed. If the solar gains are not well considered, the HTC is underestimated, with a non-negligible error.

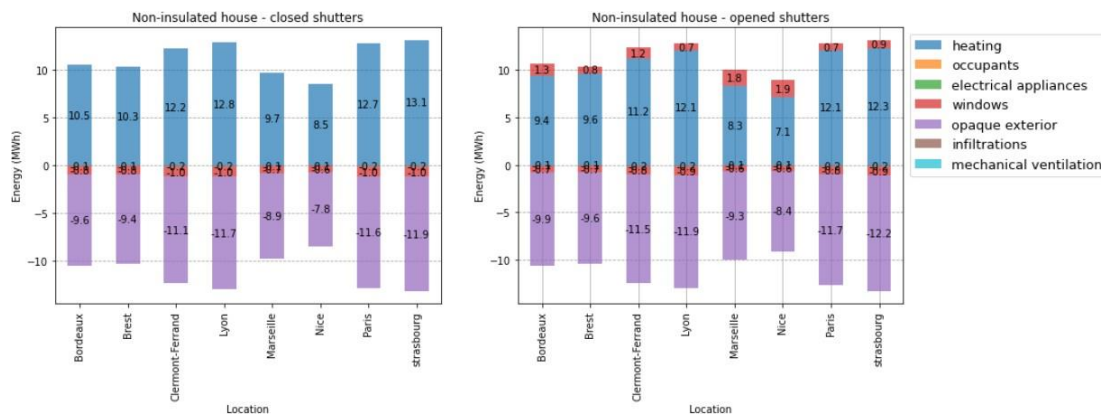


Figure 4. Energy balance – non-insulated house – closed shutters (left) and opened shutters (right).

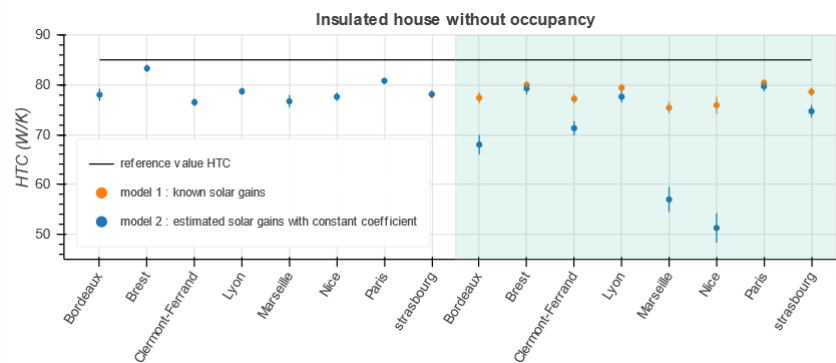


Figure 5. HTC assessment – insulated house without occupancy – closed shutters (left) and opened shutters (right).

For the uninsulated house without occupancy, the difference between the results of linear regressions (1) and (2) is much smaller than for the insulated house. A variability of HTC between each weather climate is nevertheless observable.

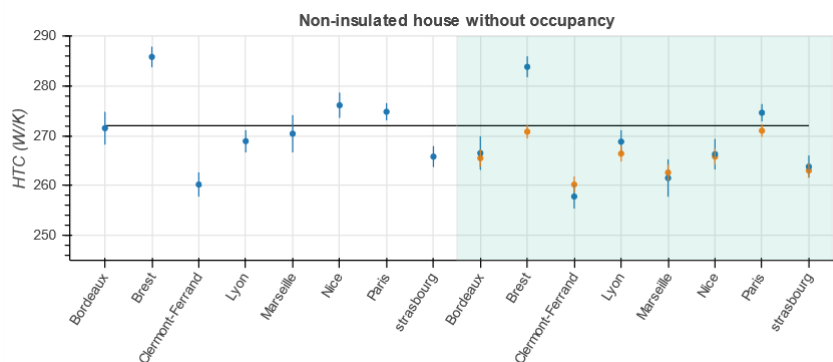


Figure 6. HTC assessment – non-insulated house without occupancy – closed shutters (left) and opened shutters (right).

3.2. Occupancy impact

Figure 7 compares the energy balances between the insulated and uninsulated house for an open-shutter occupancy scenario with four people. The heating power gain predominates in the case of the uninsulated house and the internal and solar gains have therefore less impact than in the well-insulated house. In the case of the well-insulated house, the internal heat gains, in particular the heat gains from

electrical appliances, are not negligible in the heat balance of the building. For a climate with average sunshine such as Lyon, the share of internal heat gain in the insulated house is 41% of the total heat gain, compared to 15% for the house without insulation.

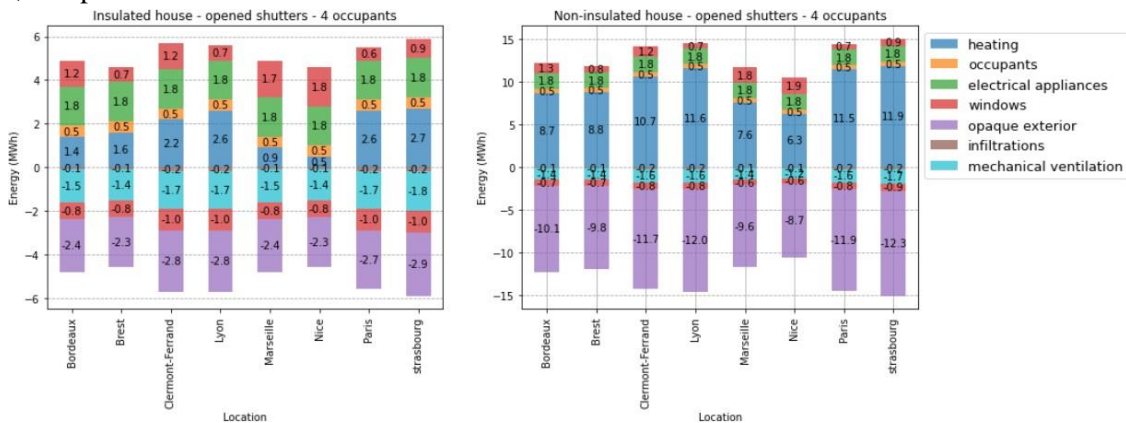


Figure 7. Energy balance – opened shutters – insulated house (left) and non-insulated (right).

In the same way as for the impact of solar gains, the impact of occupancy on the HTC estimation is studied with models (1) and (3) in Figure 8.

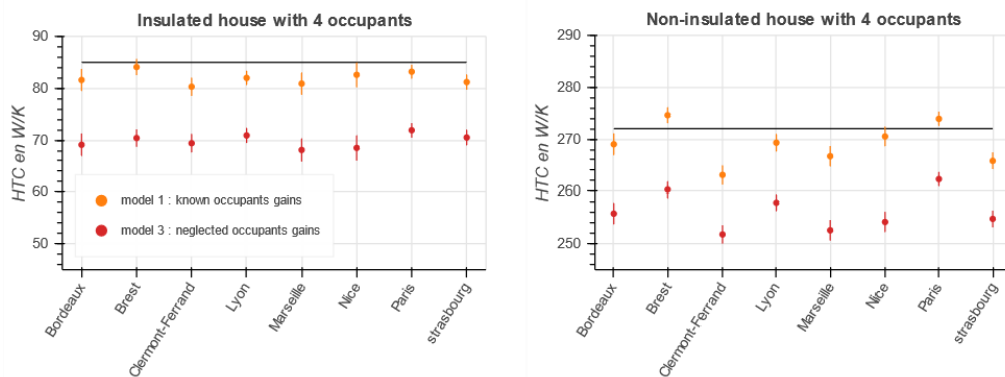


Figure 8. HTC assessment – house with 4 occupants – insulated (left) and non-insulated (right).

4. Discussion

When the house is unoccupied, the methods for estimating the HTC do not avoid the variability of the weather, but limit the impact of the solar gains by closing the shutters, which is a strong constraint for methods in the presence of the occupants. However, according to the results obtained for a well-insulated house, the solar gains represent an important part of the thermal balances and have a strong impact on the HTC estimation. The assumption of a constant solar opening coefficient is insufficient to take the solar gains into account. Modelling the solar gains must therefore be improved with a more detailed consideration of the position of the sun and the geometry of the windows, for example [14].

The internal gains proportion in the energy balance for a well-insulated house is also significant, especially the heat input from electrical appliances. This important share due to electrical appliances is mainly explained by the selection of many household appliances and audiovisual equipment for the occupancy scenarios, and also by the assumption that all electrical consumption is released as heat input. Nevertheless, the results of the HTC estimation reinforce the fact that they are to be considered because in the case they are neglected, the HTC is strongly underestimated. In the perspective of this work, particular attention will be paid to the consideration of occupancy, including its modelling and the detection and estimation of the number of occupants.

The study shows that the linear regression model with the assumption of a constant coefficient for solar aperture for the estimation of HTC is adapted only for certain typology of building, the poorly

insulated house in this study case. Some perspectives will be to find the applicability of this method in terms of building typology and climate zone.

Finally, the energy balances make it possible to quantify the impact of the various inputs influencing the thermal behaviour of a building during occupancy and to guide the choices in terms of parameter modelling and the choice of numerical model for the calibration of the data. If a regression model can be sufficient for a poorly insulated house, a more detailed model is expected for a well-insulated house.

5. Conclusion

During this work, a numerical parametric study was performed to estimate the impact of solar gains and internal loads on the estimation of HTC thanks to linear regression method. Under specific conditions, these simple models allow to estimate the HTC, i.e. poorly insulated house. For the other typologies, these models have shown their limits and it is necessary to develop more advanced models. For the future, it is necessary to widen the study case with more variability of buildings, level of insulation and glazed surfaces. Different methods will have to be tested to better consider solar gains and internal gains while remaining compatible with tests in occupation.

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